Simpson Weather Associates
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October 8, 2013

Defense Technical Information Center
8725 John J Kingman Road, Suite 0944
Fort Belvoir, VA 22060-6218

RE: Annual report under Grant No.: N000141110450

Dear Sir/Madam:

Enclosed please find our annual report under the above grant. Please let us know if you have any questions.

Yours sincerely,

Mary Morris

Mary Morris
Contract Administrator

Enclosure: Annual report

Investigation of the Representation of OLEs and Terrain Effects Within the Coastal Zone in the EDMF Parameterization Scheme: An Airborne Doppler Wind Lidar Perspective

Annual Report
Under Grant No.: N000141110450

Covering the Period:
1 July 2012-30 June 2013

Submitted by:

Simpson Weather Associates, Inc.
809 E. Jefferson Street
Charlottesville, VA 22902

Prepared by:

G.D. Emmitt, Simpson Weather Associates, Inc.
Ralph Foster, University of Washington
Stephan de Wekker, University of Virginia

07 October 2012

20131015002

INTRODUCTION WITH GOALS

The goal of our segment of the Unified Physical Parameterization for Extended Forecasts DRI is to provide observations related to the partitioning of atmospheric boundary layer (ABL) fluxes into two contributions: eddy diffusivity and vertical mass fluxes (EDMF). In addition to the field campaign, the goal is to validate the existing EDMF expressions and to propose alternatives or modifications to those formalisms.

These goals are being pursued using data sets obtained from the CIRPAS Twin Otter flown in two differing regions: off the coast of California near Monterey and over portions of the Dugway Proving grounds in Utah.

OBJECTIVES

The general objective is to collaborate with NRL (Wang) and UCI (Khelif) to use airborne sensors to probe the ABL for organizing structures such as OLEs and LLJs and, using models when appropriate, construct algorithms that would relate space-based sensor observables to the varying structure dependent ABL fluxes. Two regions have been used to collect data for the evaluation and modification of the EDMF formalisms:

1. In areas of neutral to stable ABLs capped by cloud cover ranging from zero to 100%, measure the fluxes at the air-sea interface using the TODWL and CTV instruments flown together near the California coastline in September 2012.
2. Using the MATERHORN experiment at Dugway, UT in October 2012 as an opportunity to expand the DWL data base to include ABL surveys in complex terrain as a comparison to the ABL over cold water. Note that the MATERHORN was co-funded by ONR (Ferek).

As this research has progressed, we have added a modeling component to better understand the implications of ABL structures being revealed by the TODWL during the September and October 2012 field campaigns.

APPROACH

The work on objective one above continues as we examine several cases in 2013 where the CTV was operating adequately and the ABL contained OLEs and LLJs needed for our investigation. The first important step was to navigate the data from the two systems so that their data sets could be joined. This was not as easy as it seemed since the CTV did not fly faithfully directly below the Twin Otter.

The second step is to compute heat, moisture and momentum fluxes for both the CTV and Twin Otter flux sensors. The computation of fluxes from the CTV will be done by both UCI (Khelif) and SWA (Emmitt).

The third step is to determine the correlations between ABL structures and the fluxes. The end product is envisioned as being a set of PDFs for mass flux contributions as a function of regional model representations of the BL including space-based observations that can be used to infer organized structures such as LLJs (ASCAT and CALIPSO) and OLEs (MODIS, VIIRS and GEOS).

Foster has begun modifying his OLE model to better understand the implication of "stacked rolls" being detected by the TODWL during flights just off the California coast. Emmitt and de Wekker are using the WRF and COAMPs models to test out their sensitivities to changes in the EDMF related to our field data. We will use the SCM provided by NRL if appropriate.

To meet the second objective, we processed several thousand wind profiles obtained with TODWL over Granite Mountain at Dugway Proving grounds, UT. The primary data products derived are the three wind components, turbulence on the scales of the illuminated sample volumes and aerosol structures (PBL depths, OLEs, incipient clouds, etc.)

After processing the TODWL data for 7 MATERHORN missions, comparisons of u,v and vertical velocities are compared to those predicted by a WRF model.

A final effort will be made to relate the fluxes measured at flux tower sites with those measured onboard the Twin Otter during flybys. During those passes the winds and aerosols were mapped by the TODWL. These data sets will be explored for relationships between the BL organization and flux intensities.

WORK COMPLETED

In the final half of year 2 on this project, we have processed more than 50 hours of TODWL data from both the Monterey and DPG areas. We have begun combining the information from the TODWL, CTV and Twin Otter sensors to establish the relationship between the local fluxes and the energetic of LLJs and OLEs. We have also begun to modify the EDMF (Eddy Diffusivity and Mass Flux) parameterization to account for the differences between thermally driven convection and dynamically driven vertical transports.

The WRF model has been setup and run for the 7 MATERHORN missions and comparisons between the TODWL wind profiles and the model profiles have been completed for one day.

The OLE model has been modified to investigate "stacked OLEs" seen in the April 2007 datasets.

RESULTS

Most of the results of our last year's research effort were reported at the DRI Workshop in Monterey in August 2013 and at a Coherent Laser Radar Conference in June 2013. Both presentations are appended to this report.

The two presentations are entitled:

> PBL structures governing the Unified Physical Parameterization formulation (Emmitt, Foster and deWekker)
>
> Airborne DWL investigations of flow over complex terrain (MATERHORN 2012) (Emmitt, Godwin, Greco and de Wekker)

In addition to the presentations provided as appendices, a report compiled by de Wekker is also attached. The material presented by de Wekker combines MATERHORN research results that were funded by ONR, ARO and NSF. This work lays the foundation for UPP related investigations that will be carried out in Year 3.

RELATED PROJECTS

ONR contract to study the utilization of Doppler wind lidar (DWL) data to quantify the contribution of organized large eddies (OLEs) to fluxes in the marine boundary layer (DYNAMO DRI (S. Harper, TPOC).

PLANS FOR YEAR 3

We have four primary goals for year 3 of this effort.

1. Finish the development of a methodology for joining airborne DWL data and in situ flux data to achieve an understanding of how the organized ABL structures modulate ABL fluxes.
2. Apply that methodology to the DWL data sets already identified and in some cases analyzed.
3. Develop an expression for mass fluxes by OLEs in the MBL that is suitable for use in numerical model parameterizations. This will be derived from flux data measured directly by the CTV (Monterey) and towers (Dugway) and associated with organized ABL structures mapped from the DWL.
4. Use the COAMPS, WRF and SCM to investigate the sensitivity of these models to the ranges of values for the "MF" term as inferred from the Monterey and Dugway data sets.

We will pursue publishing our results should the findings of this research merit this effort.

We will also prepare a work plan and budget for years 4 and 5. This plan will be submitted by the end of 2013. The primary issues to be considered will be:

Can we justify a second field project in FY 2014 that will focus upon the lidar resolved MBL structures and their impacts on fluxes? In 2012 the lidar was flown on just one good mission due to weight considerations and the desire for 5hr flights. This would not be the case in a proposed second series of TODWL/CTV flights.

What space-based data sets can be used to classify the type and degree of "organized" BL structures and thereby adjust the coefficients in the EDMF being used in global models?

What is the best flux parameterization that recognizes the differences in the mass flux traced to dry thermal convection vs. dynamically driven BL circulations?

Attachment 1

Airborne DWL Investigations of Flow over Complex Terrain
(MATERHORN 2012)
Paper presented at the Coherent Laser Radar Conference, June 2013

Airborne DWL investigations of flow over complex terrain (MATERHORN 2012)

G. D. Emmitt, S. Greco and K. Godwin

(Simpson Weather Associates)

S. de Wekker

(University of Virginia)

CLRC 2013

Barcelona , Spain

18 June 2013

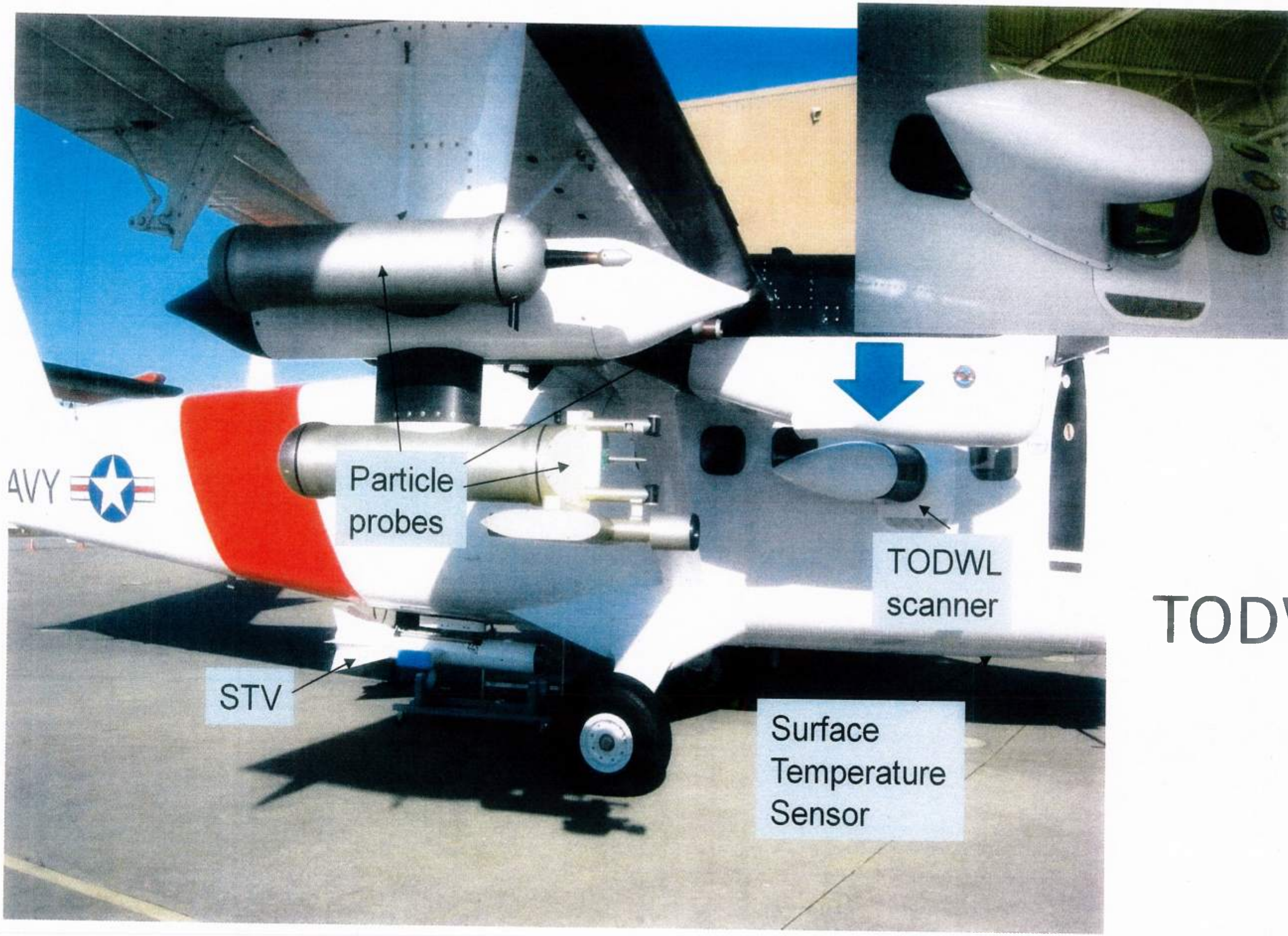
Outline

- Science objectives of the MATERHORN
- Experiment summary (TODWL data)
- WRF model
- DWL soundings on Google Earth
- WRF and TODWL data comparisons

- ***Funding provided by:***
  - ***Office of Naval Research (Ferek)***
  - ***Army Research Office (Videen)***

P3DWL for Tropical Cyclones

1.6 um coherent WTX (ARL/LMCT)
10 cm bi-axis scanner (NASA)
P3 and other parts (NRL)
Analyses software (SWA/CIRPAS)



TODWL*

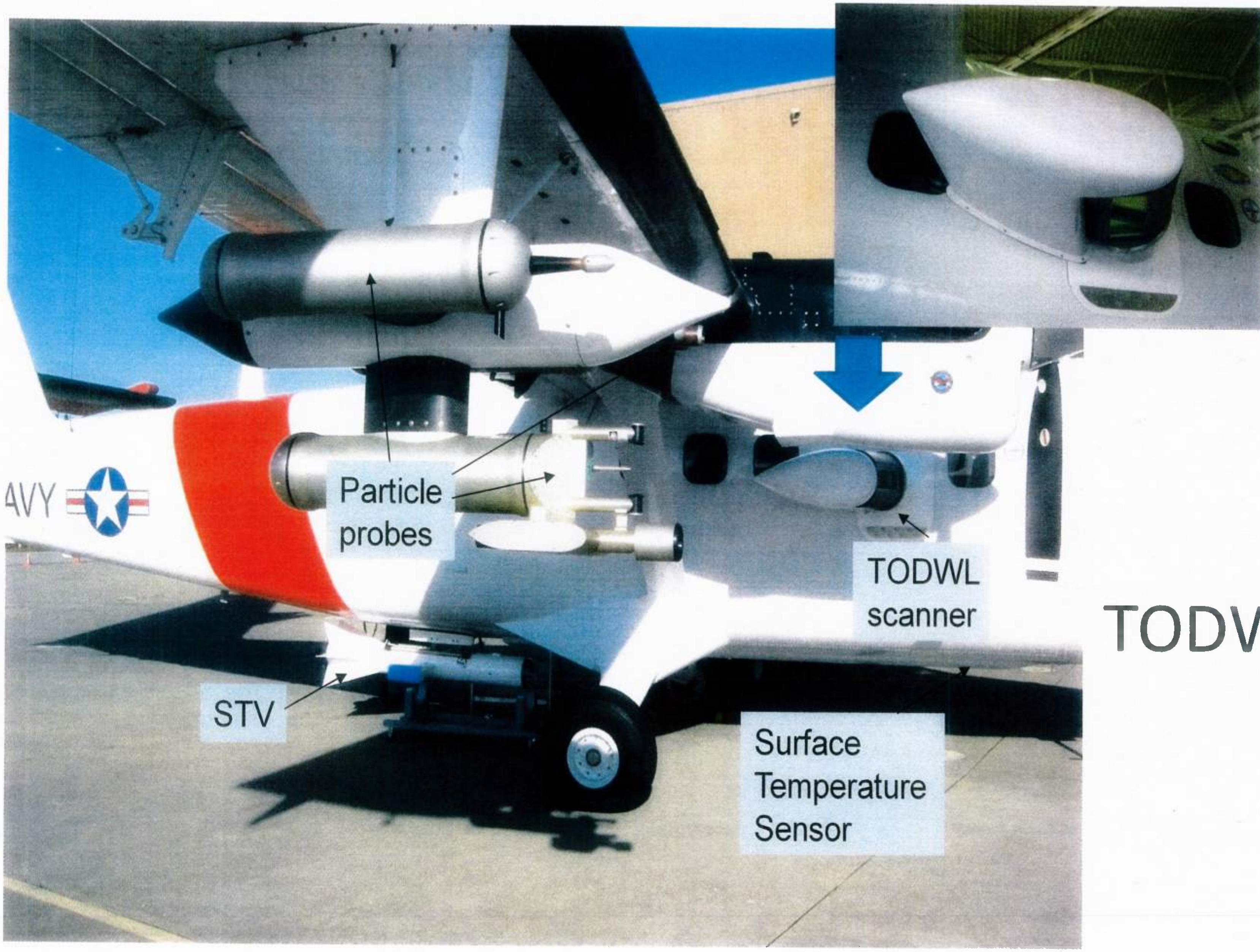
* Twin Otter Doppler Wind Lidar

TWOLF

Tornado-chasing Wind Observing Lidar Facility

Pallet Wind Observing Lidar Facility (PWOLF)

Attribute	Performance Metric	Comments
LOS resolution (applies to vertical profiles of 3D winds as well)	50 m	Range resolution to hard targets (ground or dense cloud) can be better than 10 meters.
U,V,W resolution	< 10 cm/s	< 5cm/s for stationary groundbased operations
Maximum range	6 -30 km	Very dependent upon aerosols
Time to complete full conical scan for wind profiles	~ 20 sec	
Sampling frequency	100 Hz	Integration of several shots is typical to improve range performance



Particle
probes
TODWL
scanner
STV
Surface
Temperature
Sensor
AVY

TODWL

CIRPAS Twin Otter at MATERHORN

- MATERHORN is a multi-agency research project to better understand and model atmospheric circulations in complex terrain.
  - Provide 3D context for complex terrain flow studies being conducted with towers, rawinsondes and UAVs,
- The MATERHORN also provided the opportunity to pursue Unified Physical Parameterization objectives with evaluation of EDMF parameterization over land in the presence of organized structures in daylight and nocturnal flows and katabatic flows.

Flight profile

- Navy Twin Otter based out of Salt Lake City
  - ~ 20 minute to Granite Mountain
  - climb to 12K feet (~5K feet above peaks)
- Twin Otter in Utah between 5 October and 18 October, 2012
- Missions lasted~ 4 hours
  - 7 missions yielded ~3200 wind profiles between surface and 3400 meters.

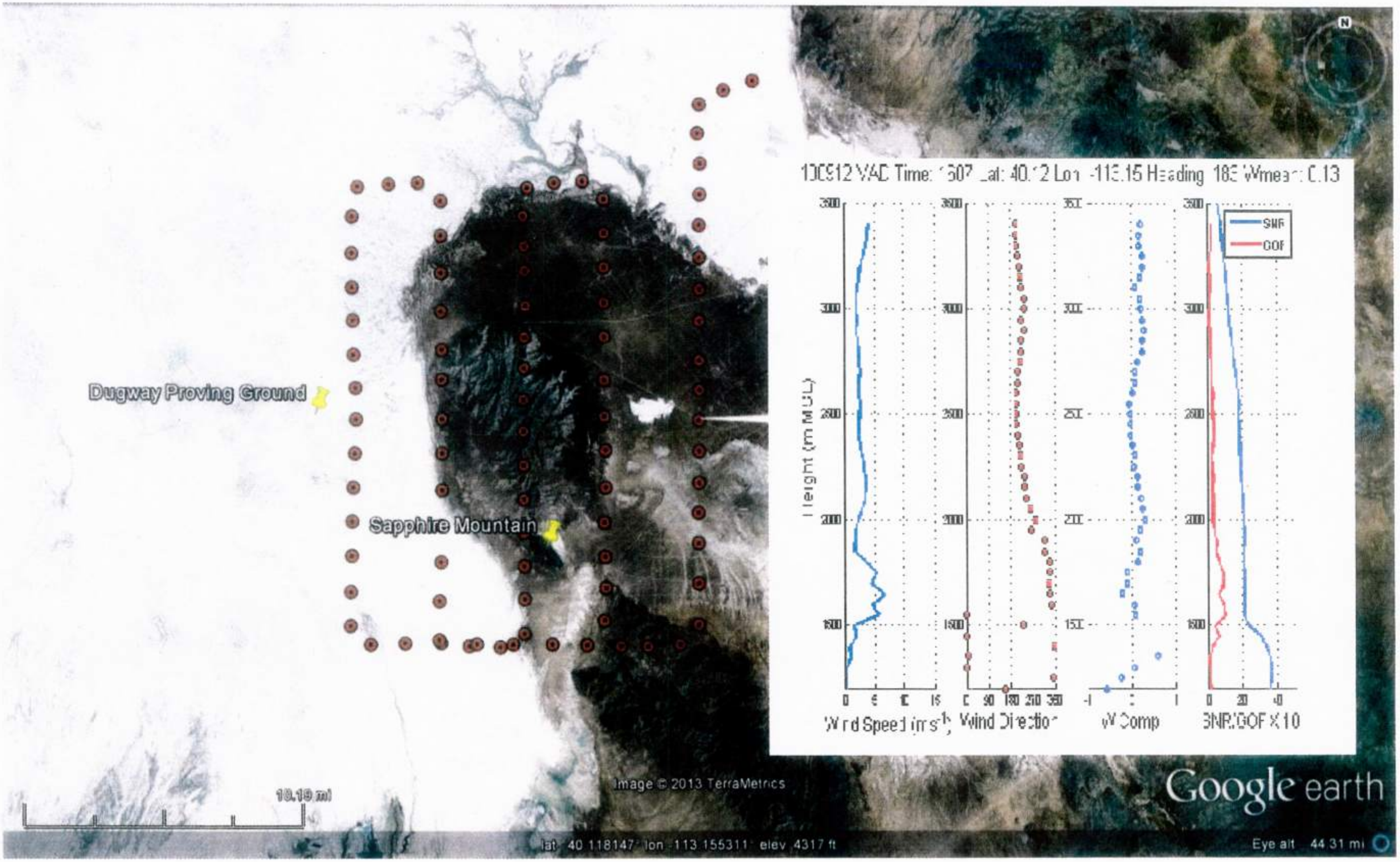
TODWL data products

- Downward conical scans (12 point step stare)
- Off-nadir angle of 20 degrees
  - 20 -25 seconds for full 360 scan (~ 1 -1.2km)
  - U,V,W with 50 m vertical resolution
    - precision (U,V) ~ .10 m/s ; precision(W) ~ .15 m/s
  - SNR (aerosols)
- Nadir samples
  - 5 seconds between conical scans
  - 50 m vertical resolution with w precision ~ .10 m/s`
- Structure prospecting
  - Straight ahead and down 3 -6 degrees

3-D Doppler Wind Profiles near Dugway, UT during MATERHORN 2012 10/06/2012

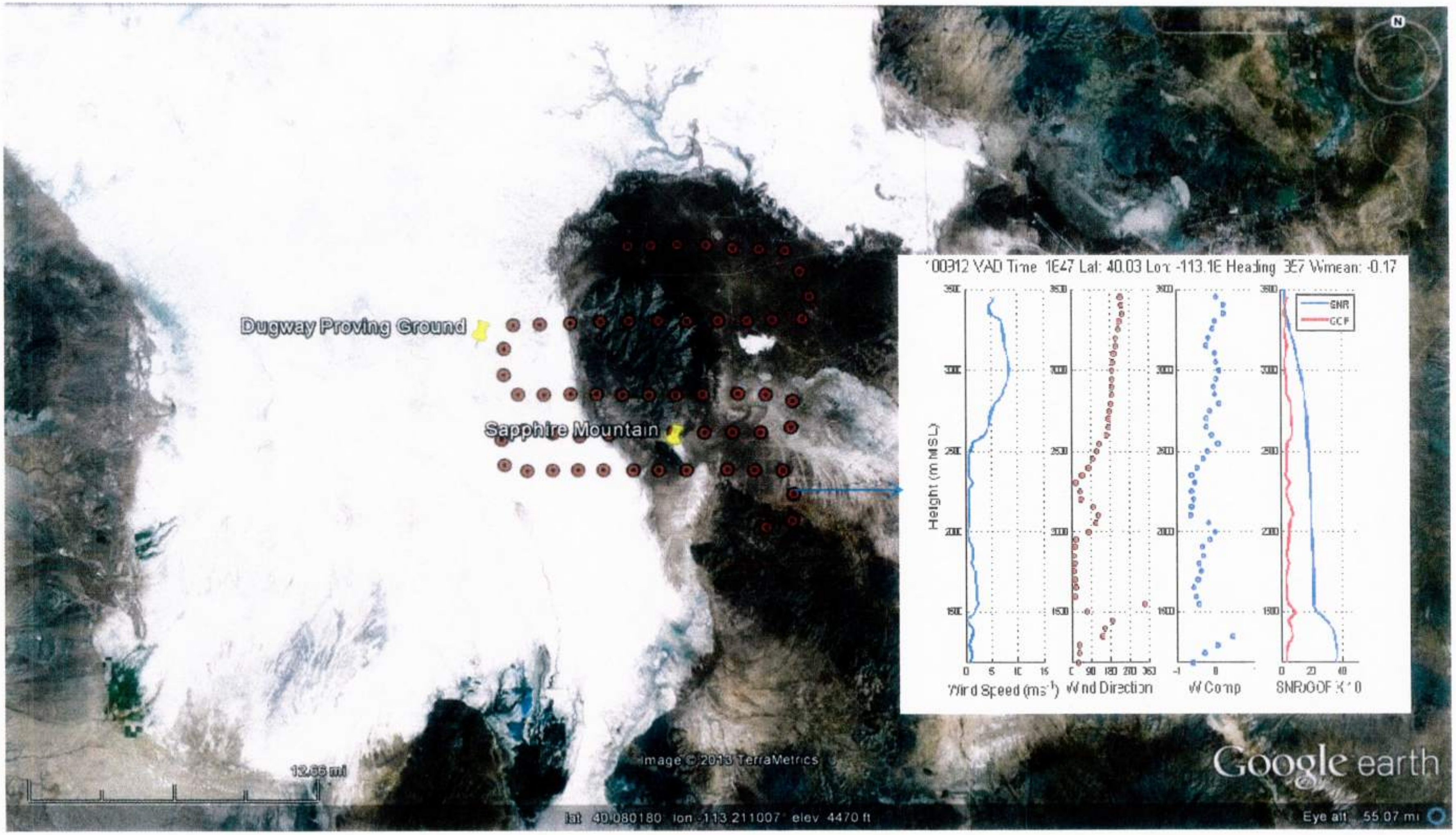
10/06/2012 N-S Legs.kmz

MATERHORN 2012 TODWL N-S Legs on October 9, 2012
1601 - 1641



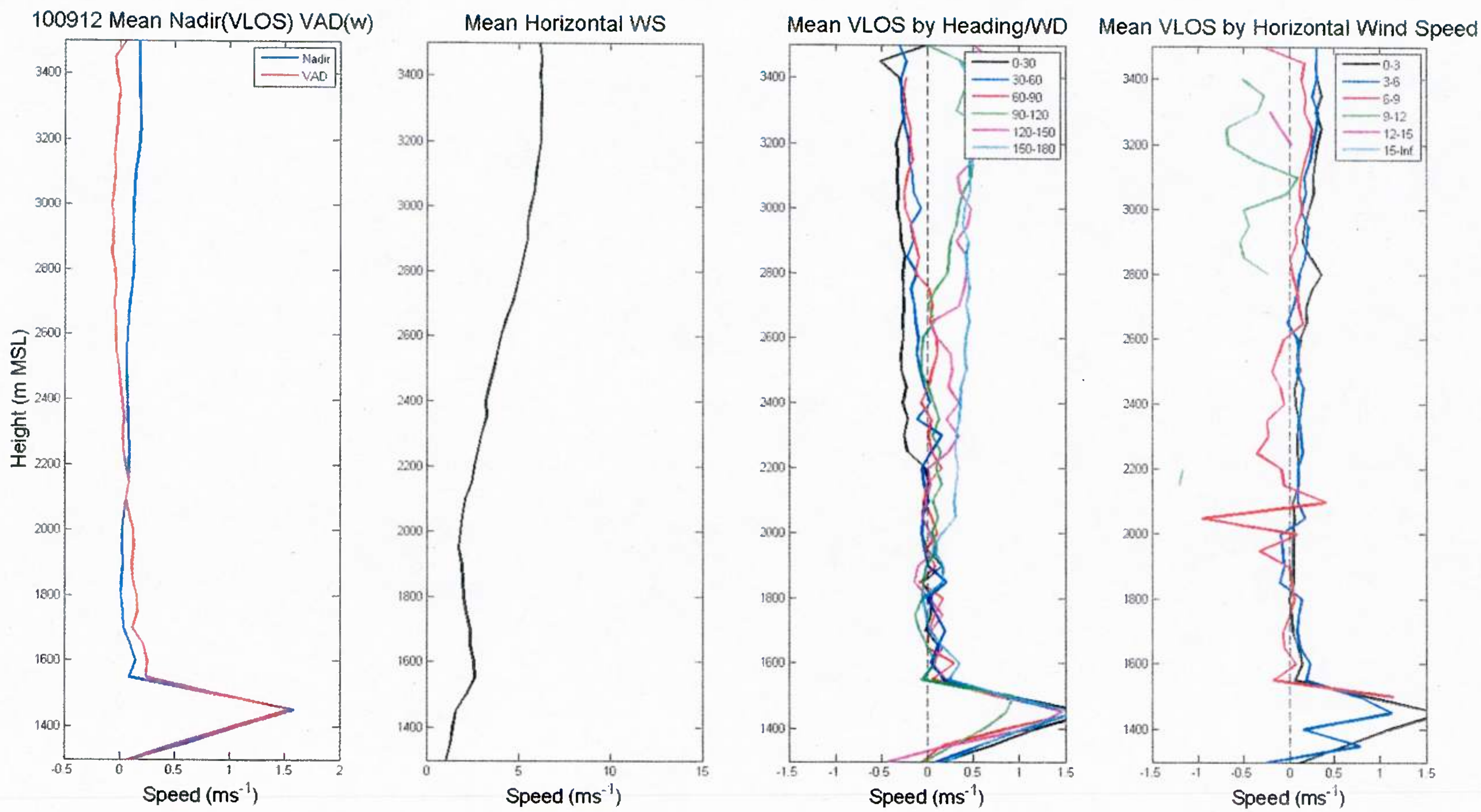
*** - Provided by Simpson Weather Associates, NRL, ONR, ARL and ARO**

MATERHORN 2012 TODWL E-W Legs on October 9, 2012
1646 - 1711

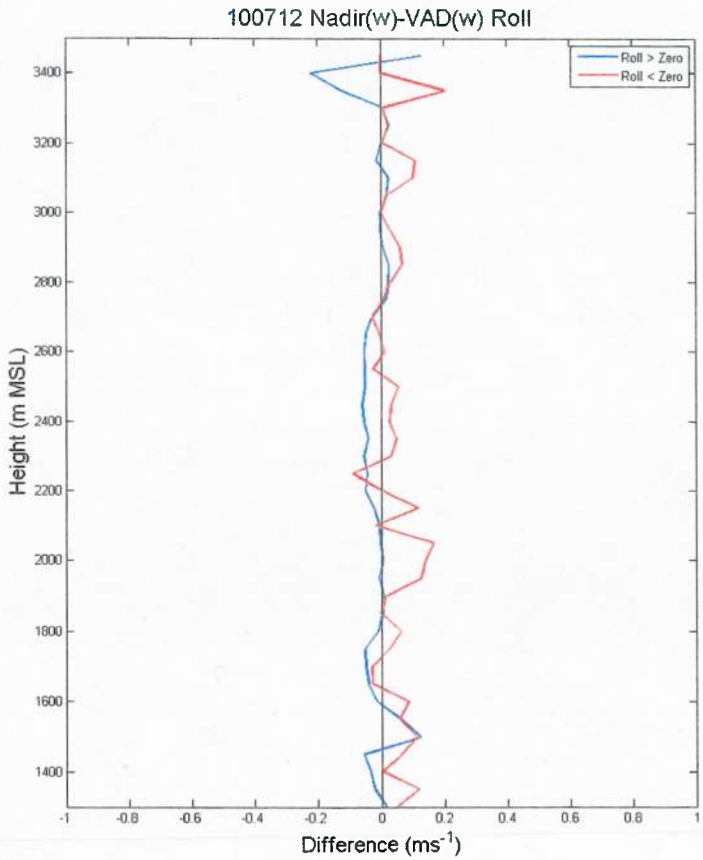


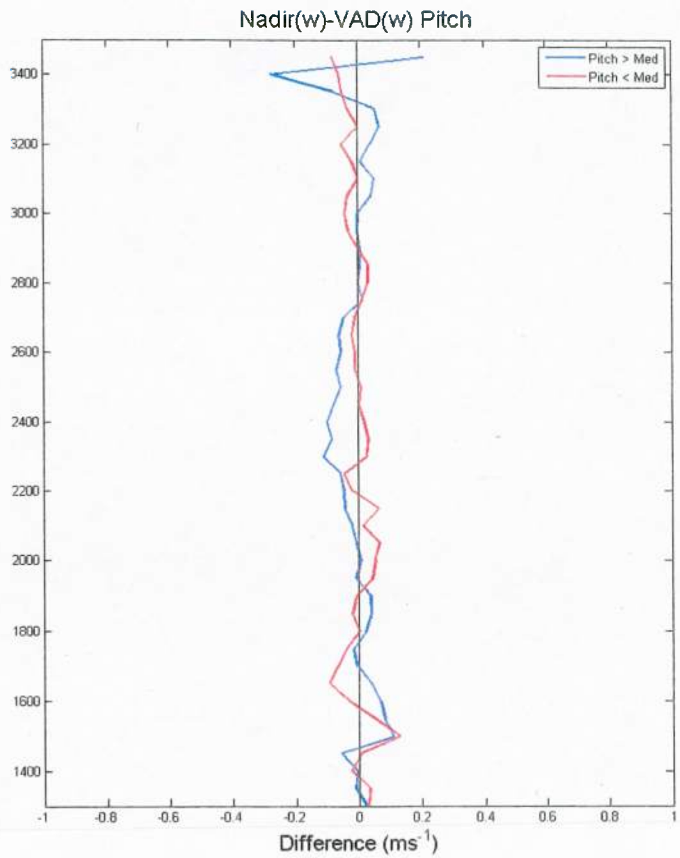
* - Provided by Simpson Weather Associates, NRL, ONR, ARL and ARO

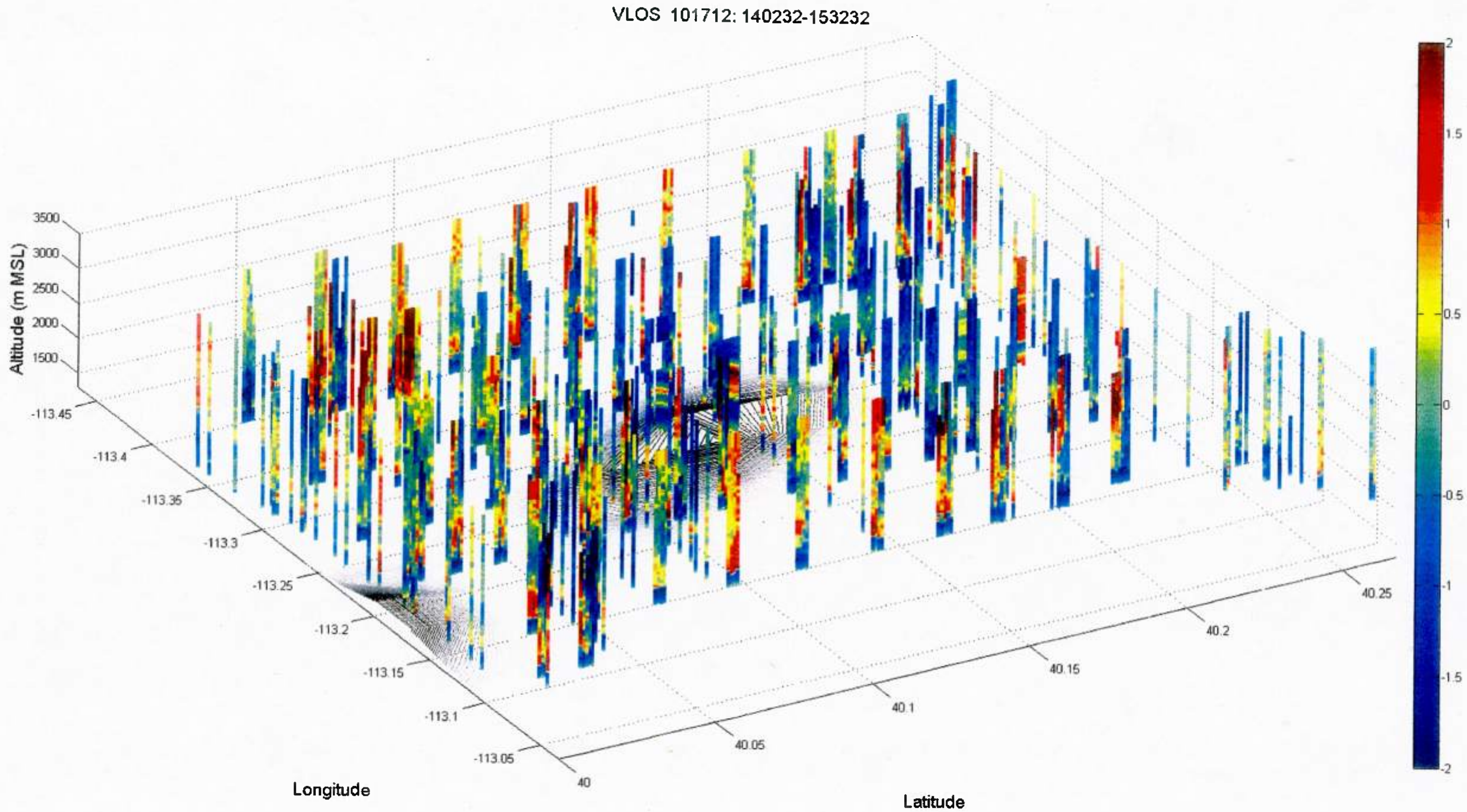
Vertical wind component



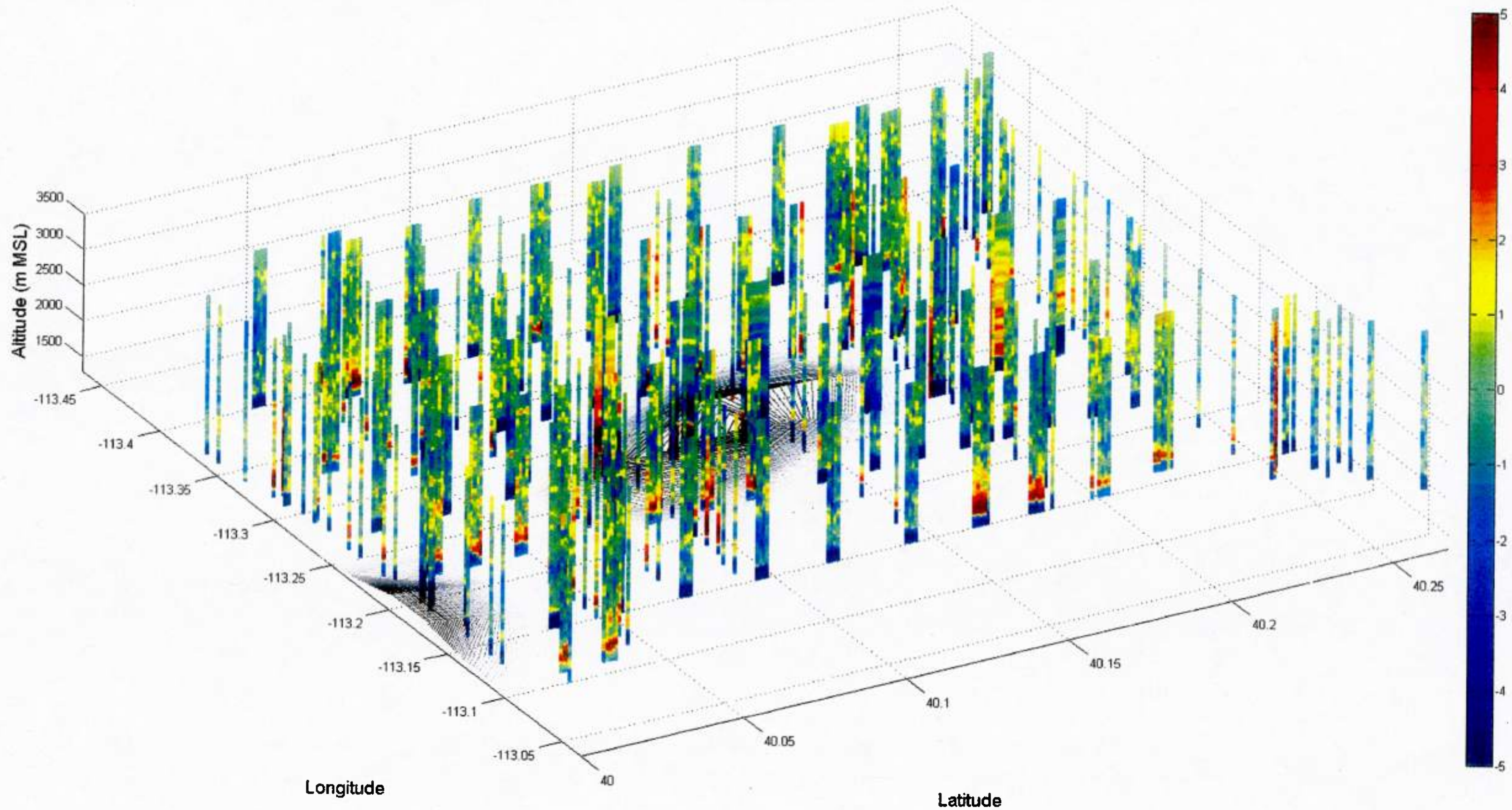
W_{nadir} as function of roll and pitch






VLOS 101712: 140232-153232
Altitude (m MSL)
3500
3000
2500
2000
1500
-113.45
-113.4
-113.35
-113.3
-113.25
-113.2
-113.15
-113.1
-113.05
Longitude
40
40.05
40.1
40.15
40.2
40.25
Latitude
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2

SNR 101712: 140232-153232

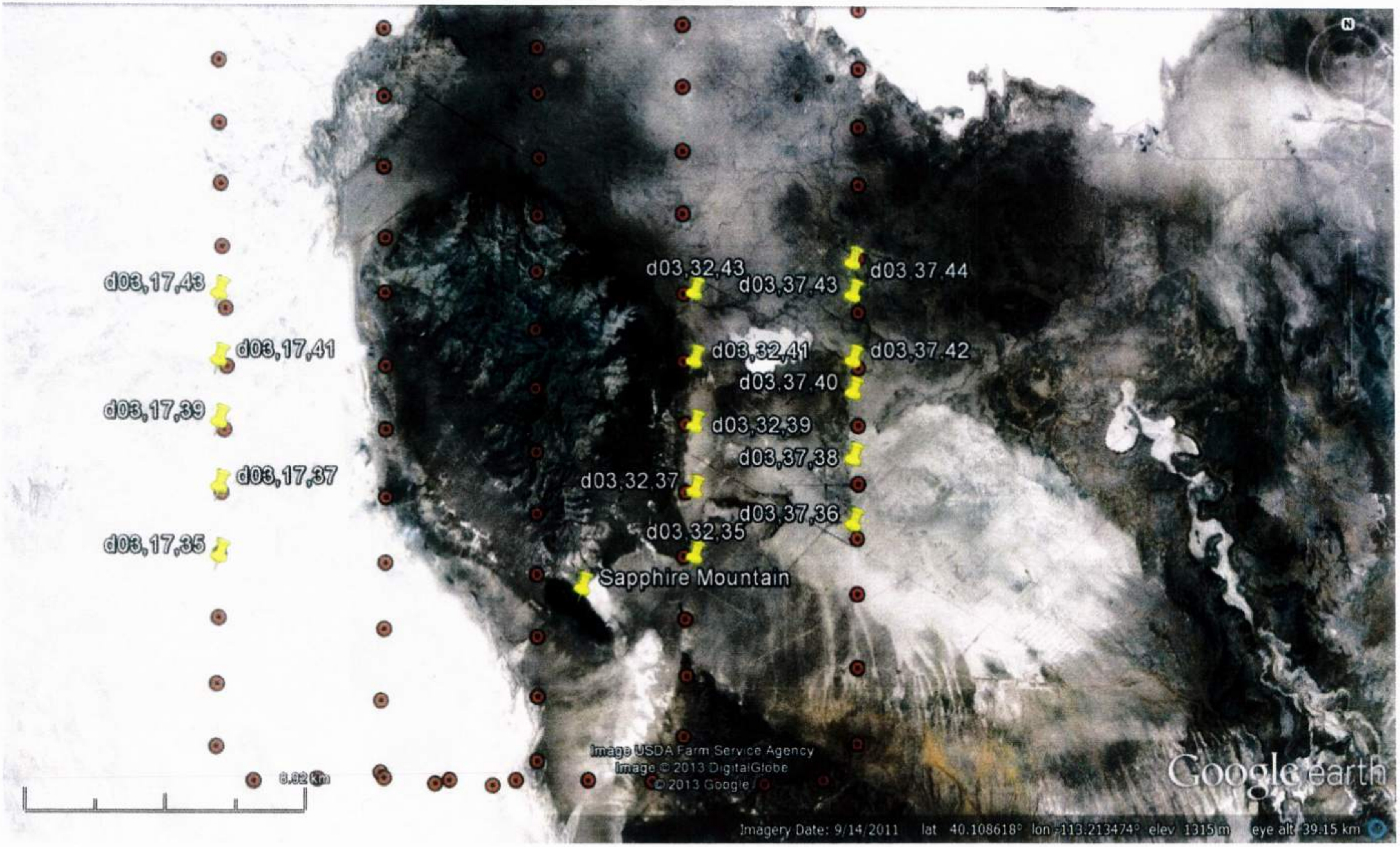


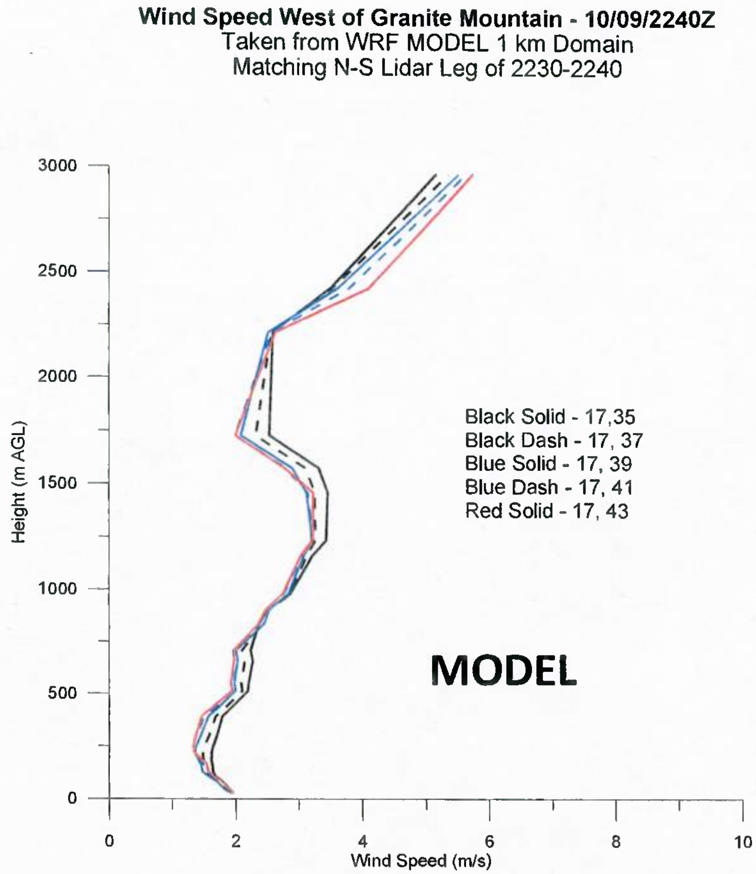
WRF Model

- WRF* Version 3.3 to generate 3D winds
- 3 Nested Grids – 9 km, 3 km, 1 km
- Dugway, Utah area
  - Used for previous DoD studies, flight test campaigns
  - Reasonably representative of theaters of interest
    - Domain: 35 km x 35 km horizontal x 42 vertical levels
  - 10 minute time steps available and utilized for some of the analysis

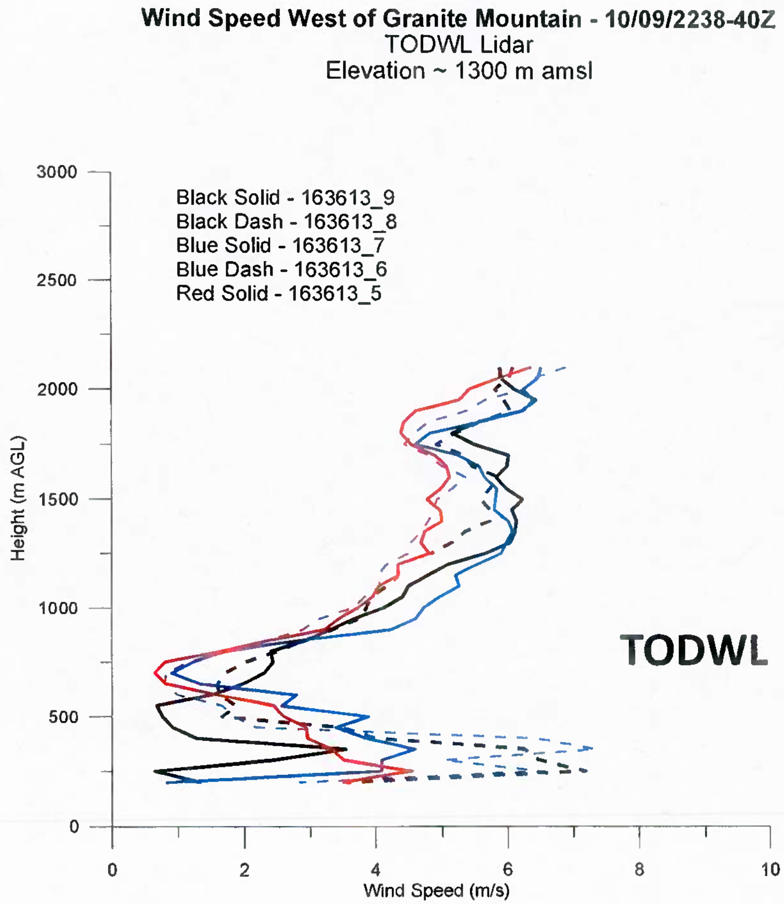
* Weather Research Forecasting Model

N/S legs flown at 3400m (MSL) on 10/9/12



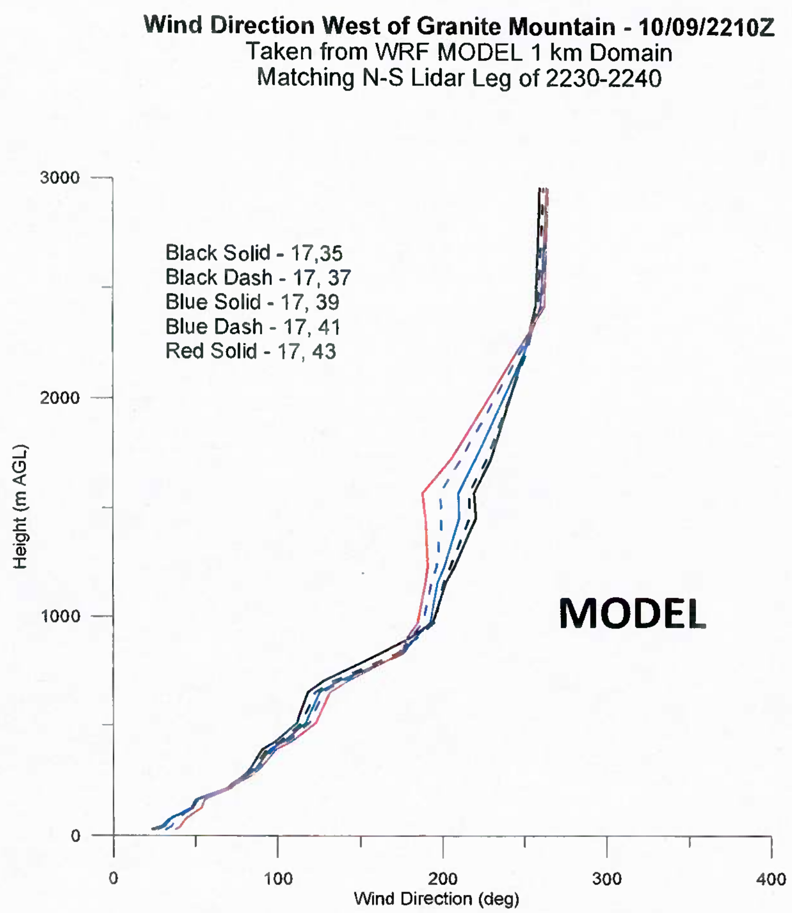


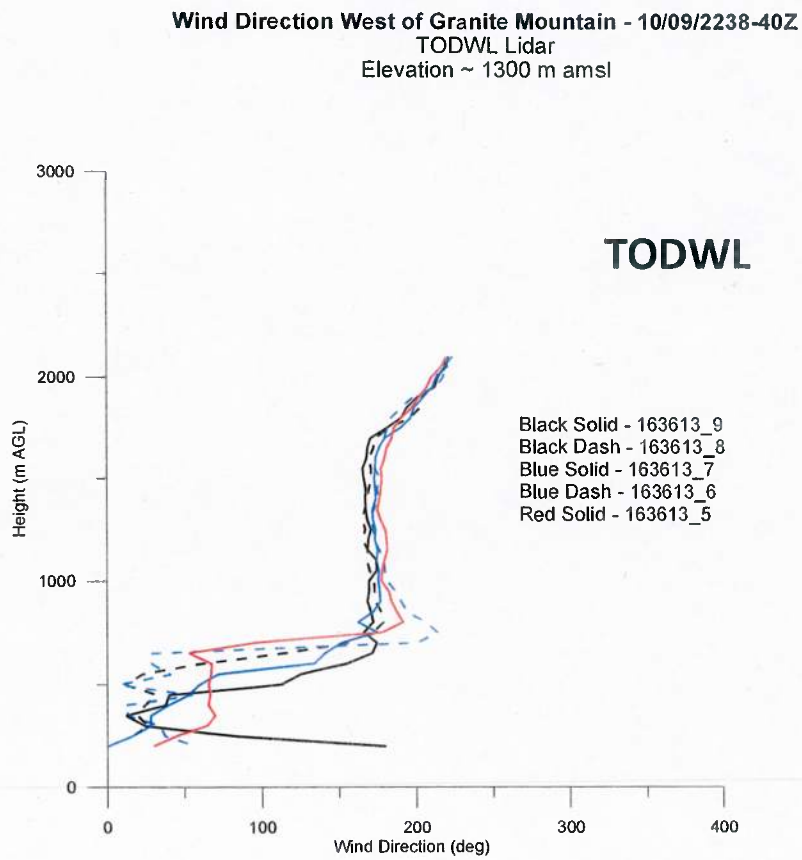
West_Upwind by ~6km



Wind Speed

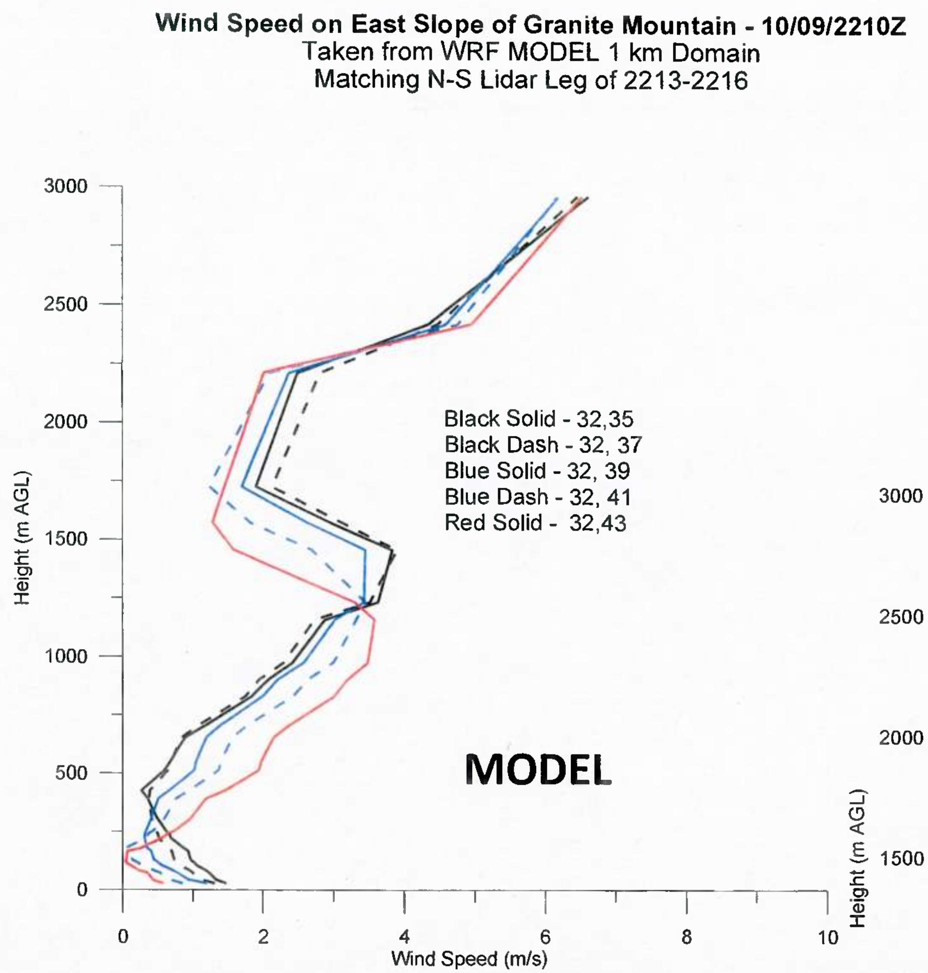
West_Upwind by ~6km

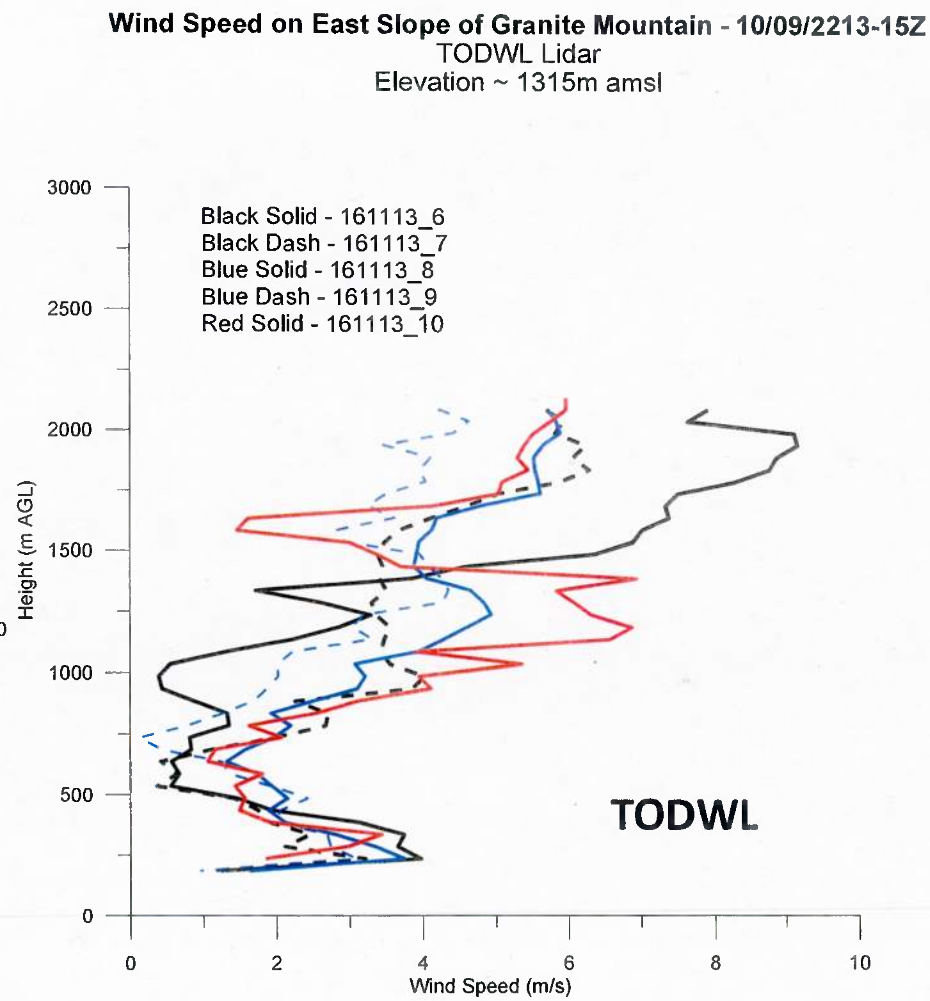




Wind Direction

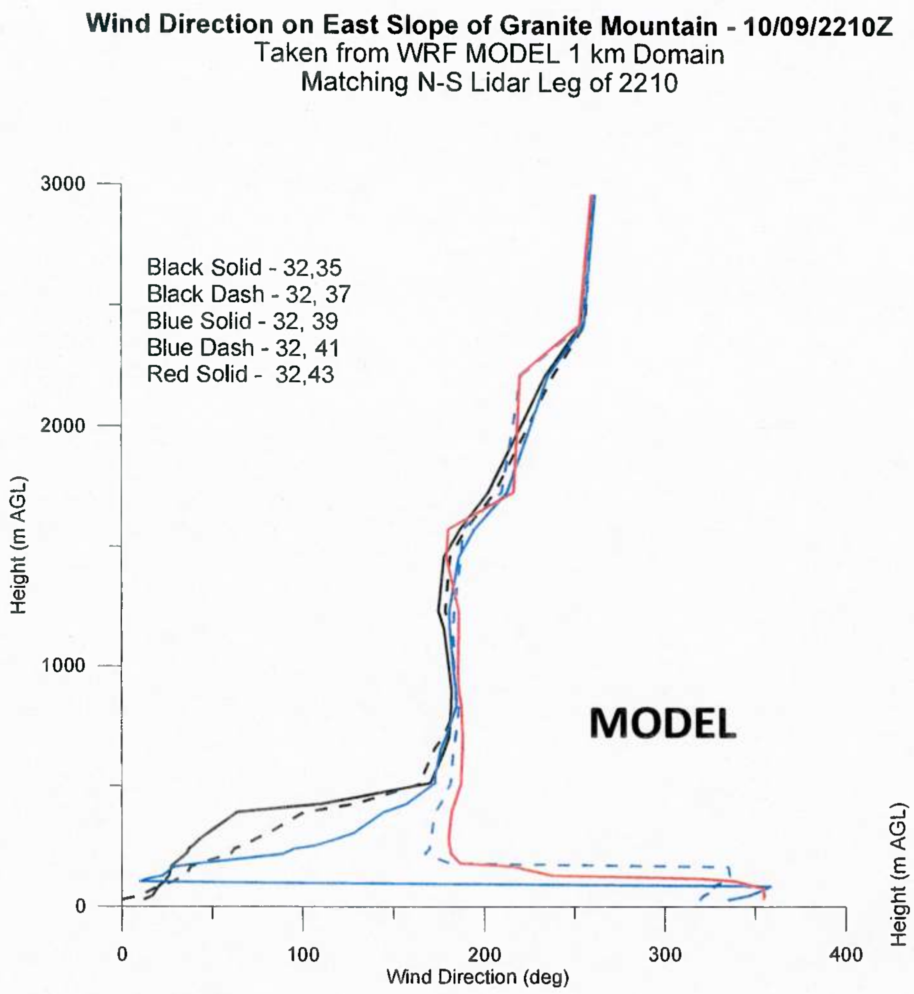
East_slopes

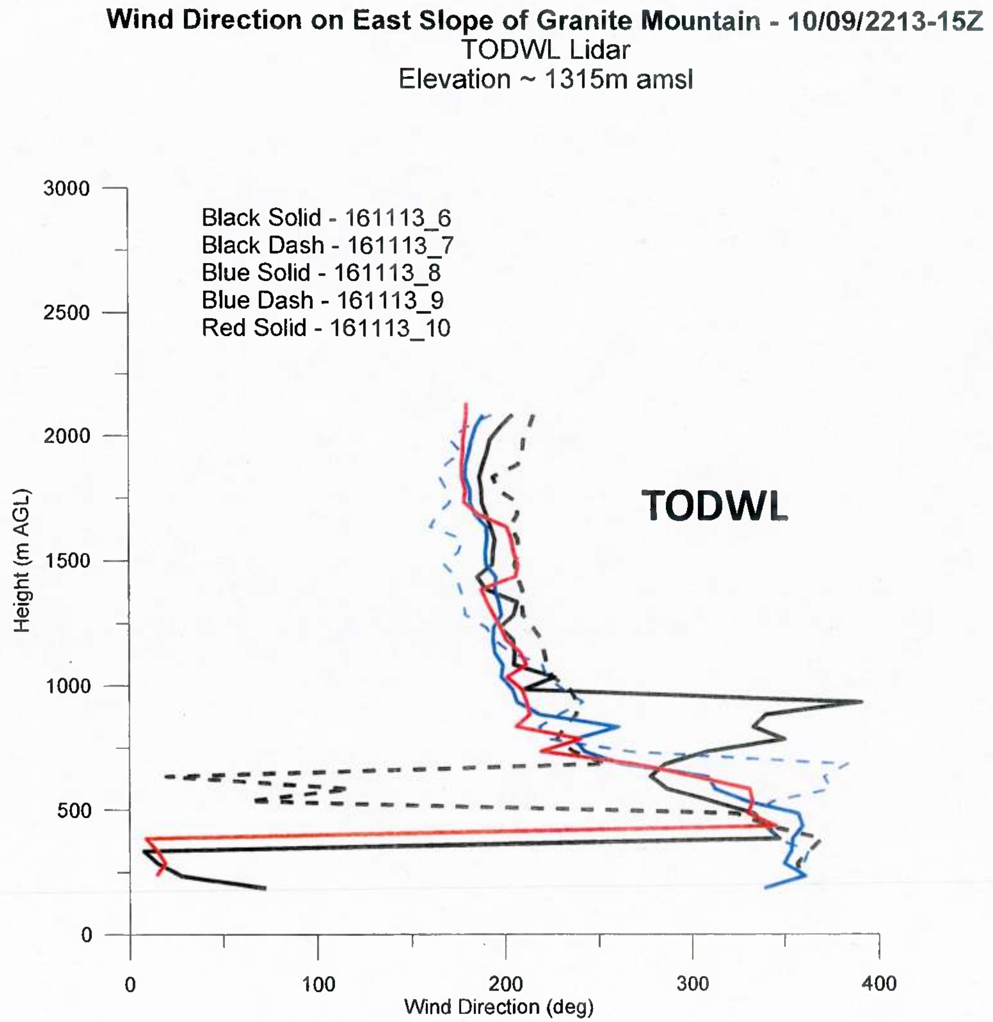




Wind Speed

East_slopes

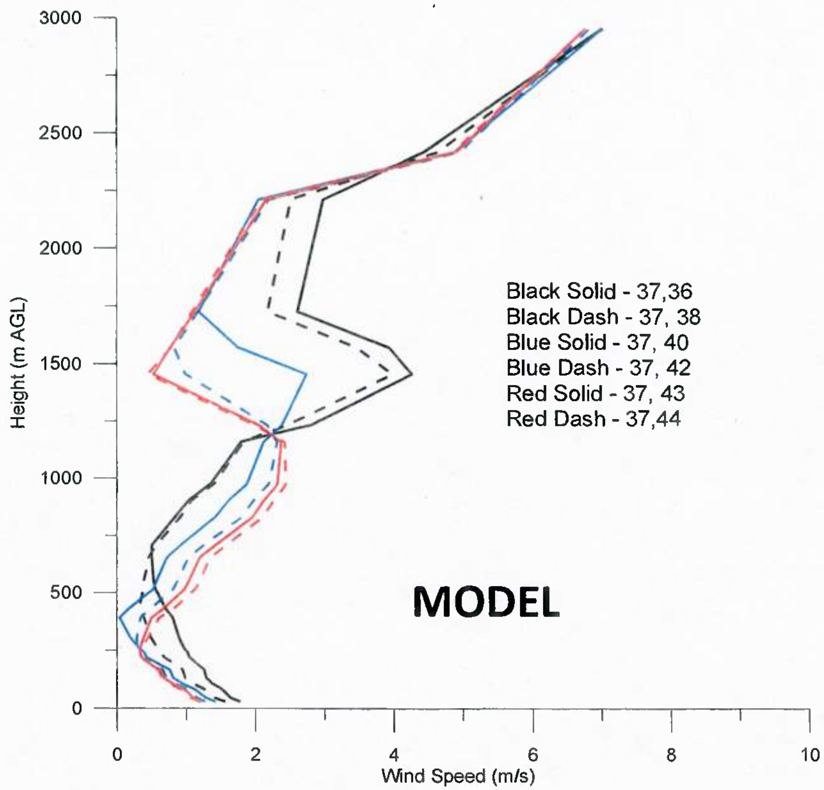




Wind Direction

East_downwind ~6km

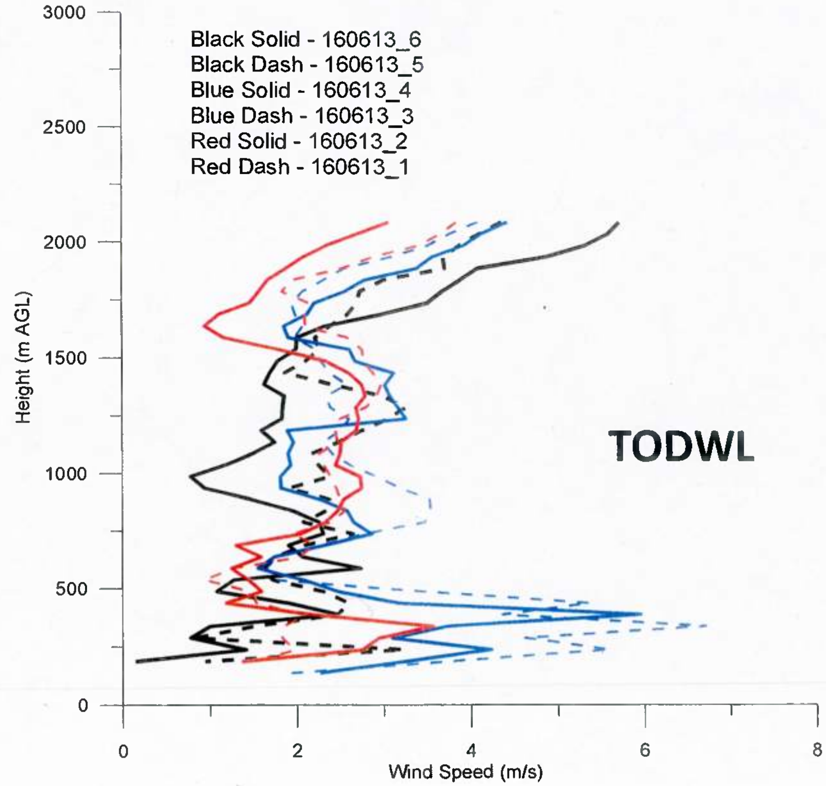
Wind Speed East of Granite Mountain - 10/09/2210Z
Taken from WRF MODEL 1 km Domain
Matching N-S Lidar Leg of 2213-2216



MODEL

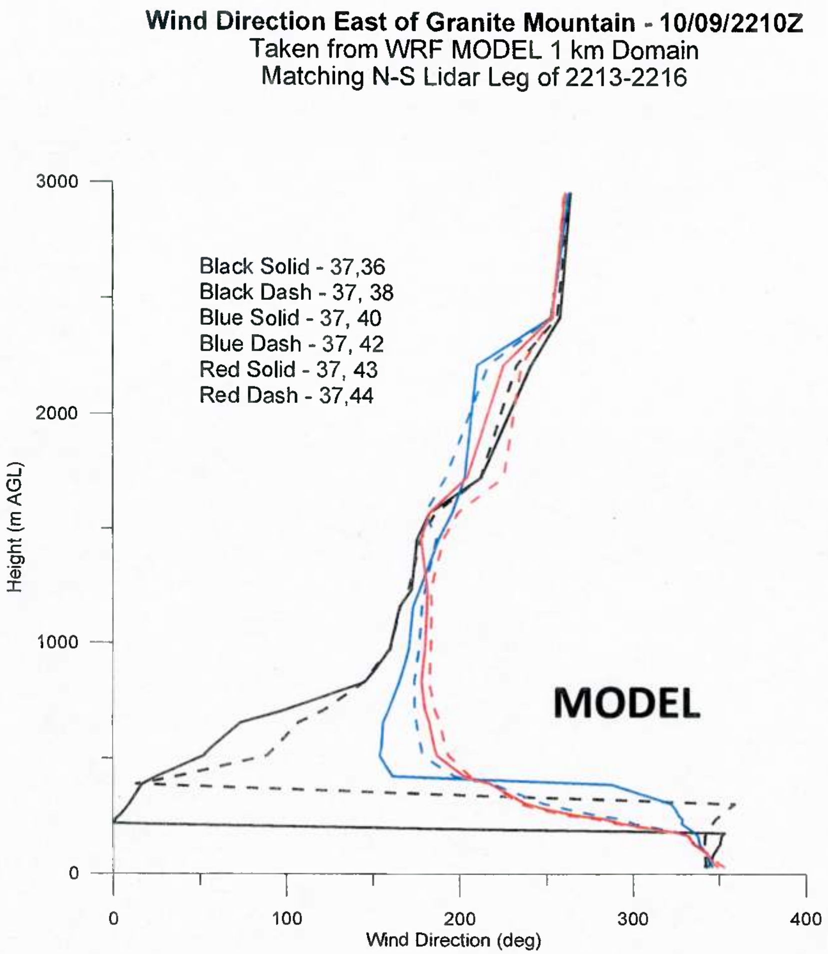
Wind Speed

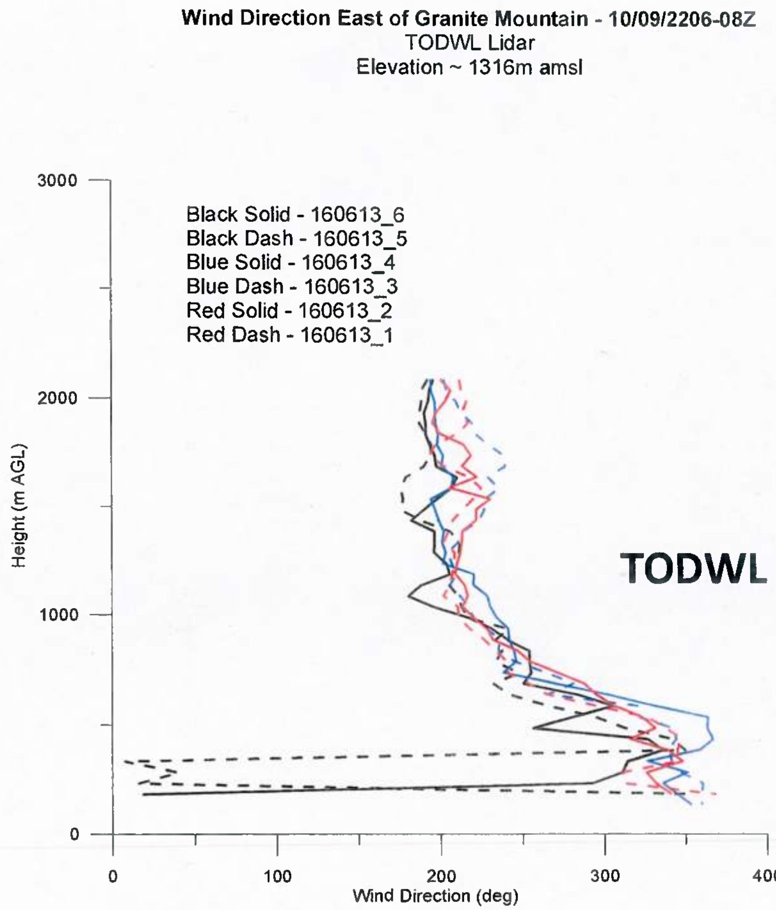
Wind Speed East of Granite Mountain - 10/09/2206-08Z
TODWL Lidar
Elevation ~ 1316m amsl



TODWL

East_downwind ~6km





Wind Direction

Summary

- Weather patterns provided several different flow patterns over study area (Dugway Proving Grounds)
- TODWL performed very well with no unscheduled down times.
- Other data were provided by UAVs, tethered balloon, ground-based DWLs, instrumented towers, rawinsondes and smoke releases.
- TODWL data is supporting model (WRF/NCAR and WRF/Pu) validation and development being conducted at UVa and SWA.
- TODWL data combined with flux tower data addressing KDMF parameterization schemes
- Data also being used to improve algorithms for Precision AirDrops.

Attachment 2

PBL Structures Governing the Unified Physical Parameterization (UPP) Formulation
Paper presented at the project workshop in Monterey, CA, August 2013

PBL structures governing the Unified Physical Parameterization formulation

G. D. Emmitt, SWA
R. Foster, APL UWash
S. De Wekker, UVA

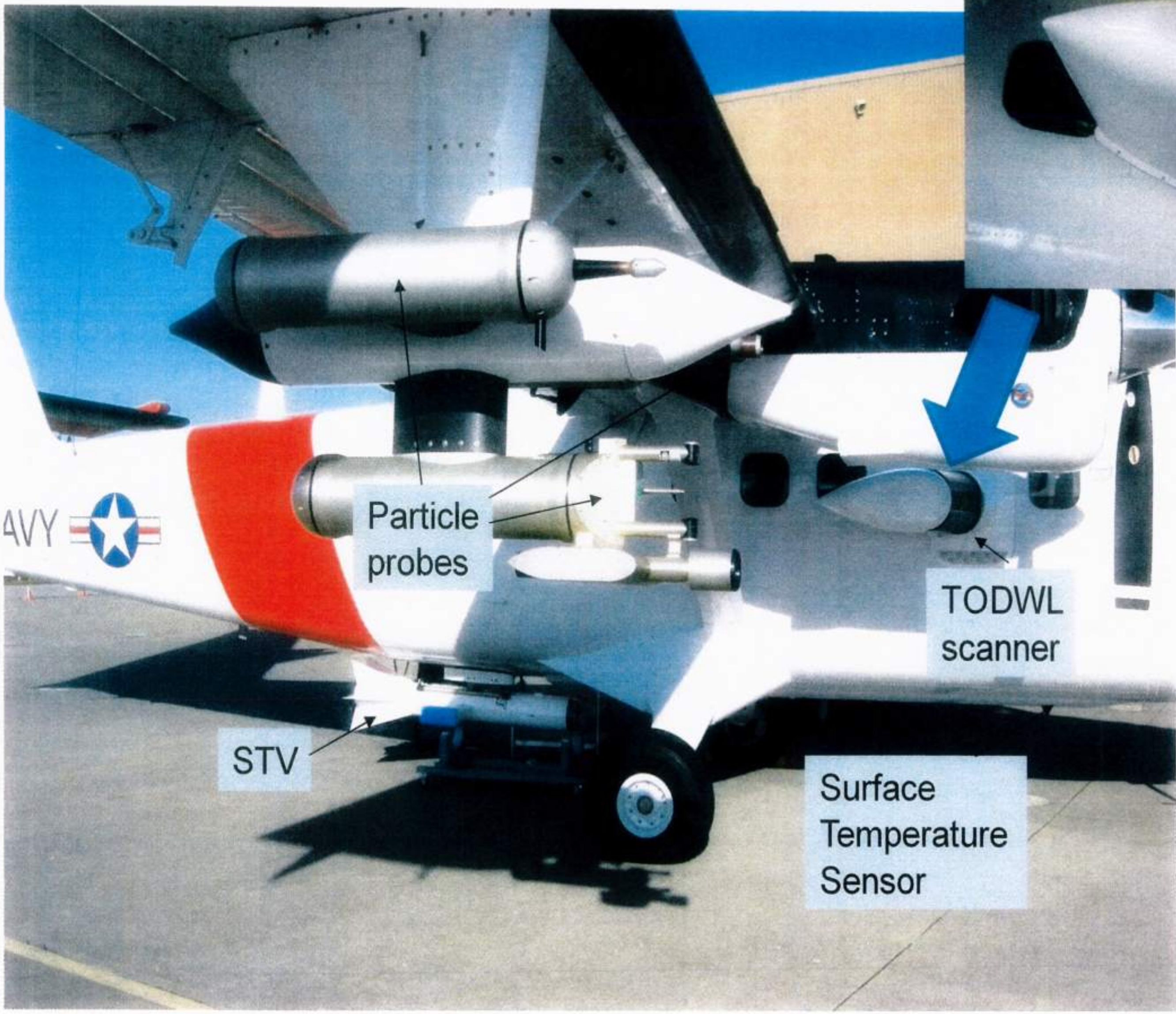
Overview

- Objectives of the September 2012 field campaign
- Description of observing system and data
- Summary of DWL data collection out of Monterey, CA
- Summary of DWL data collection at DPG, Utah in October
- Best day data 09/30/12 as example
  - Flight path
  - Clouds
  - Vertical position record
    - Twin Otter and CTV
  - Vertical soundings
- Additional case studies
- Modeling of rolls and their relative contributions to EDMF
- Near term plans

Objectives

- Extend prior investigations (2001-2008)of LLJs and OLEs in the MBL and PBLs.
- Investigate and characterize the presence of rolls (OLEs) at the boundaries of stratocumulus topped MBLs.
- Study the potential impact on the develoment and implementation of the EDMF into forecast models.

The observing systems and strategies



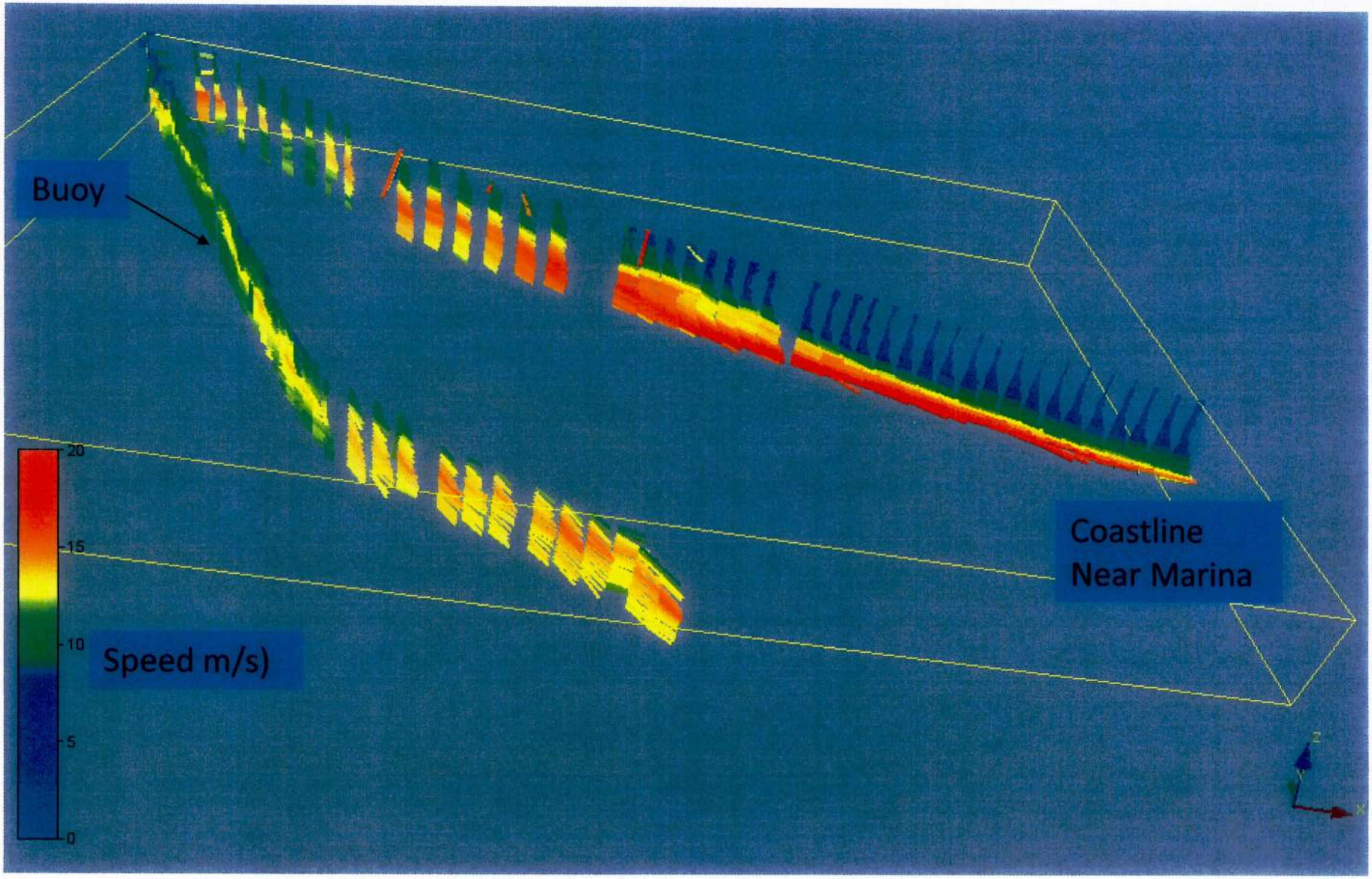
TODWL

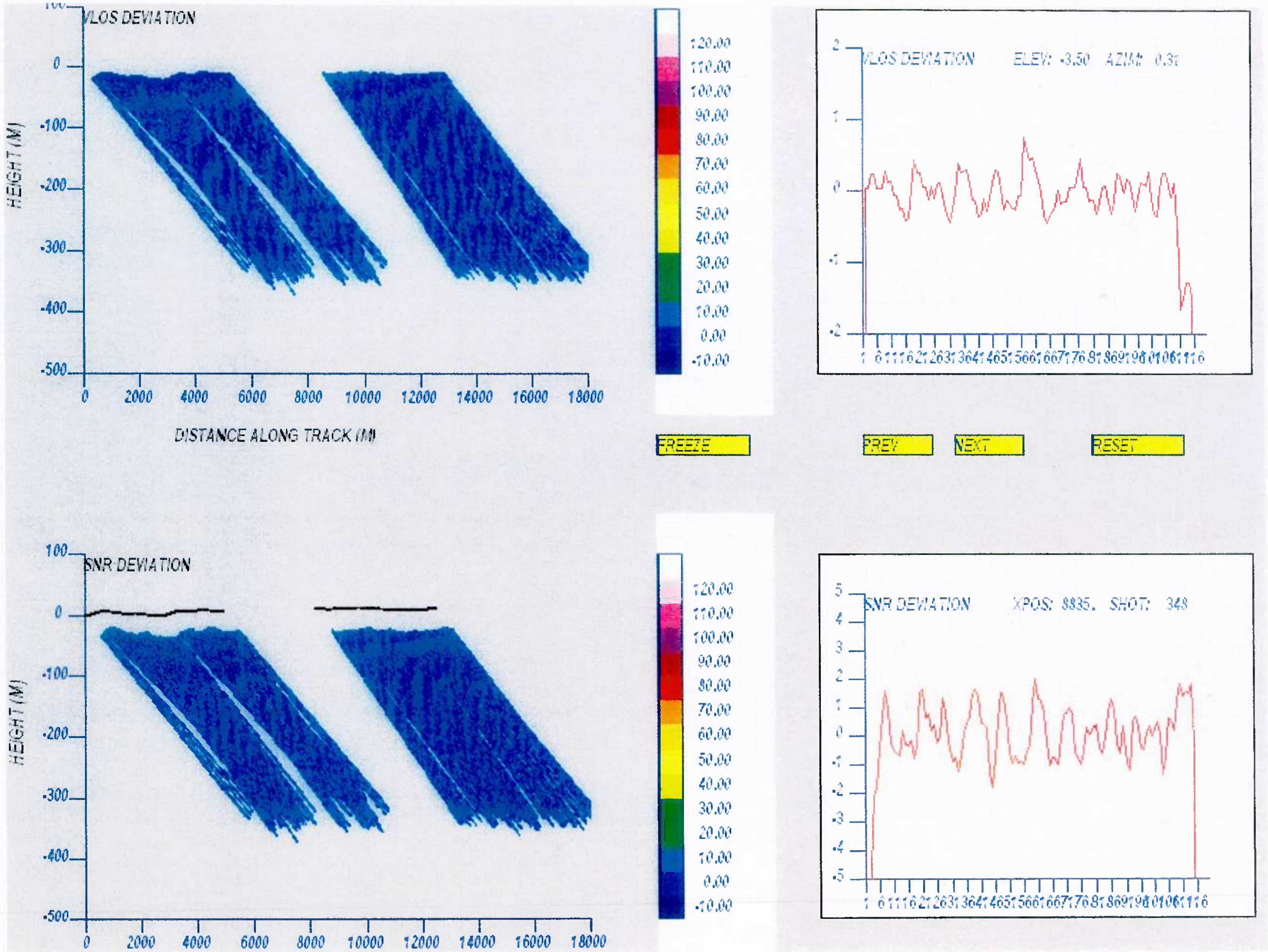
Twin Otter Doppler Wind Lidar

SWA

Attribute	Performance Metric	Comments
LOS resolution (applies to vertical profiles of 3D winds as well)	50 m	Range resolution to hard targets (ground or dense cloud) can be better than 10 meters.
U,V,W resolution	< 10 cm/s	< 5cm/s for stationary groundbased operations
Maximum range	6 -30 km	Very dependent upon aerosols
Time to complete full step stare conical scan for wind profiles	~ 20 sec	12 point step stare with .5 -2 second dwells
Sampling frequency	100 Hz	Integration of several shots is typical to improve range performance

TODWL under flight of WINDSAT on 18 April 2007 6:07 pm PST
Monterey Bay, California



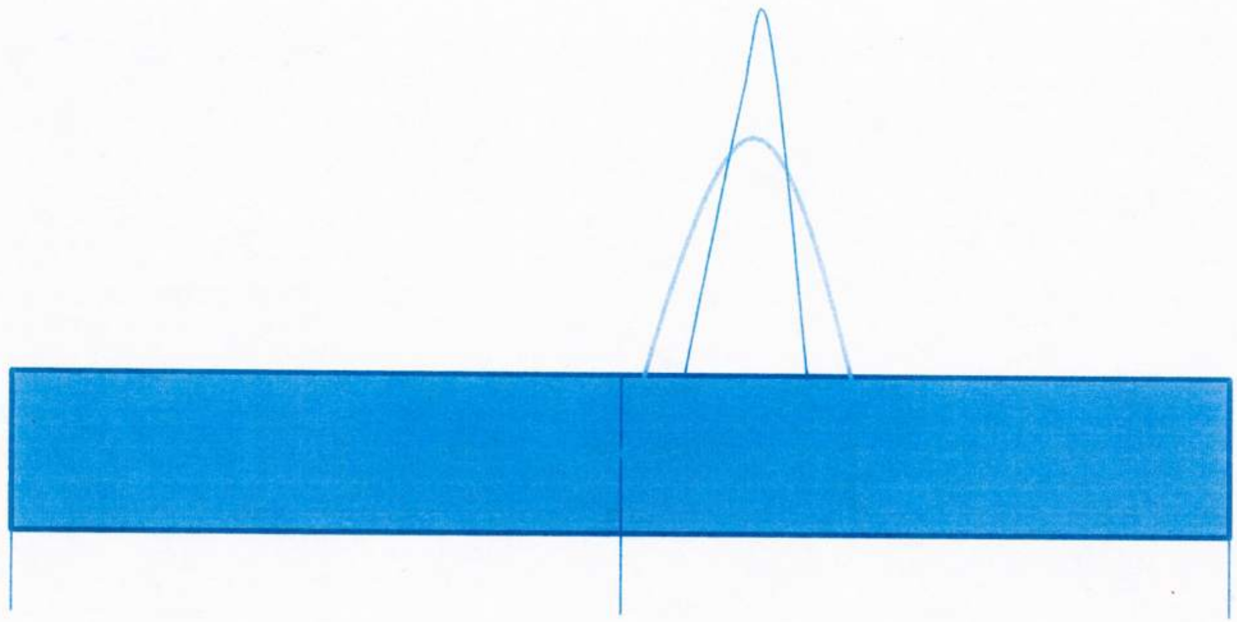

VLOS DEVIATION
HEIGHT (M)
DISTANCE ALONG TRACK (M)
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
0
-100
-200
-300
-400
-500
120.00
110.00
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
VLOS DEVIATION ELEV: -3.50 AZIM: 0.31
FREEZE
PREV
NEXT
RESET
SNR DEVIATION
100
SNR DEVIATION XPOS: 8835. SHOT: 348

CIRPAS Twin Otter
with
CTV below

Some additional information

- Feature prospecting uses a very shallow angle below the horizon (~ -1 -3 degrees for a 300m flight altitude).
  - Results in ~ 2 m vertical resolution and 50 m horizontal resolution with ~10 meter sliding sample.
  - It takes ~ 40 seconds to profile 100 meters below the aircraft.

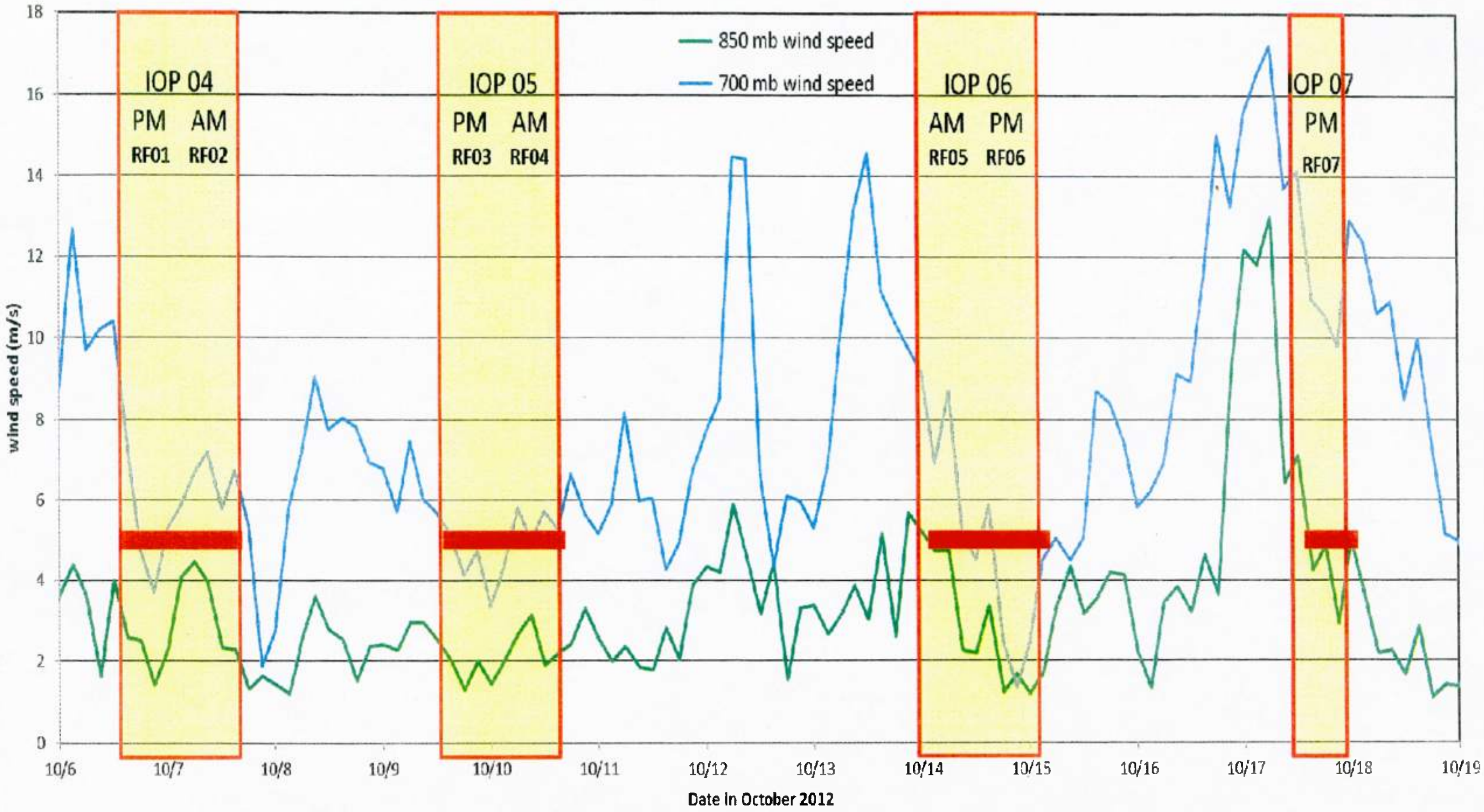
Processing lidar returns in the spectral domain



Data summary for September/October UPP field campaign with TODWL

- Three quality flights with the DWL
- One quality co-flight with the CTV (9/30).
- Two 5 hour ferry flights between Monterey, CA and Salt Lake City, Utah.
- Seven 4.5 hour flights over DPG, Utah during the MATERHORN
  - Co-funded by ONR and ARO
  - 3500 vertical profiles used to validate WRF models
  - 14 low level flights dedicated to prospecting for OLEs in the vicinity of flux towers.

Pallet Wind Observing Lidar Facility (PWOLF)



Summary of the 7 research flights conducted during MATERHORN in support of the UPP and MATERHORN projects.
Winds at 700 and 850 mb provide an indication of the magnitude of the synoptic forcing during the various flight days.
Flights were conducted during MATERHORN IOP's 4, 5, 6, and 7.

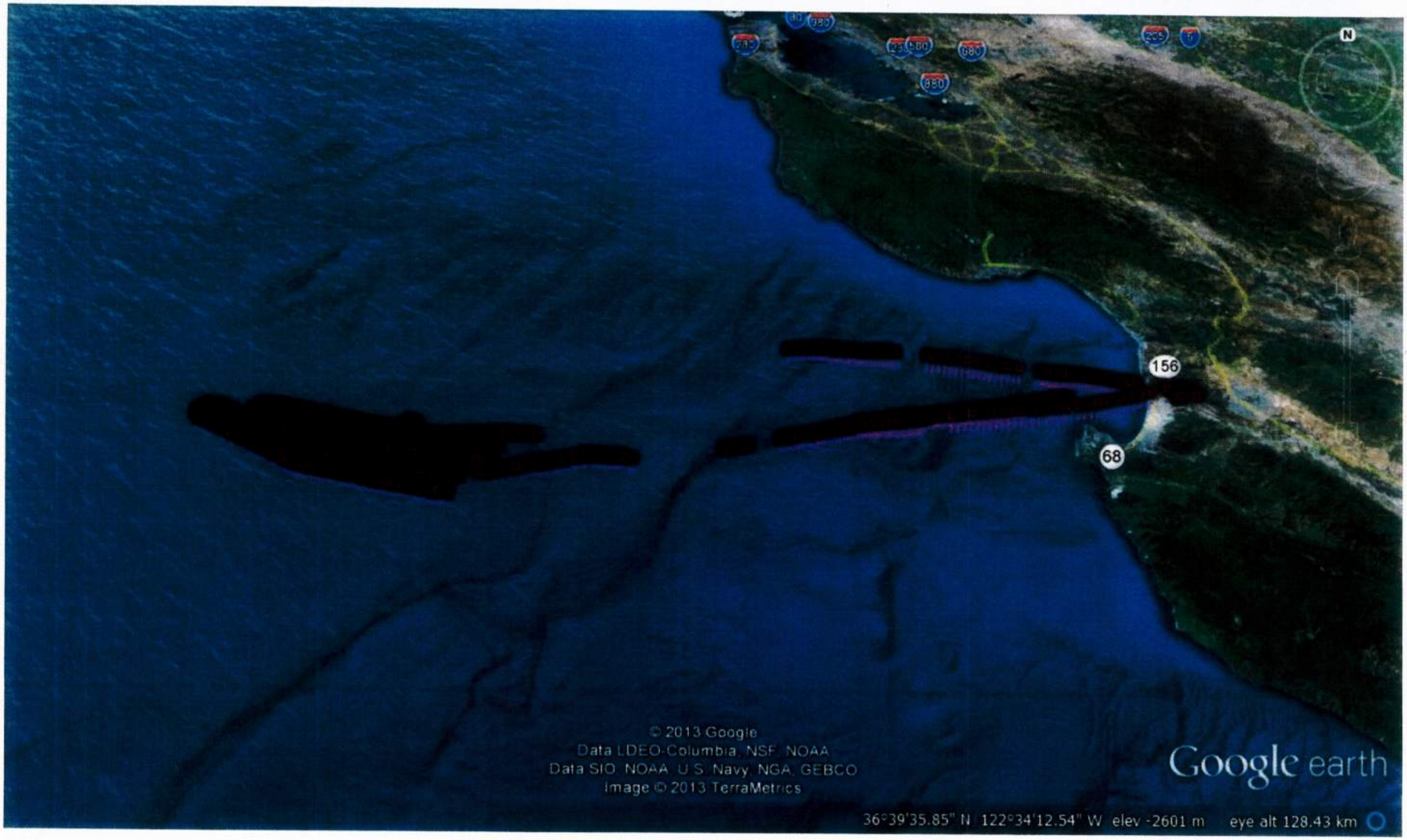
A major effort is underway to investigate the presence of organized convective structures under these different conditions and the contribution of these structures to vertical heat and momentum fluxes. These investigations include a detailed analysis of surface fluxes obtained by in-situ turbulence sensors on the many towers that were deployed during MATERHORN. A post-doc (Sandip Pal) and a graduate student (Mark Sghiatti) at UVA will contribute to this effort during the next year.

9/30/12 UPP: Monterey case study

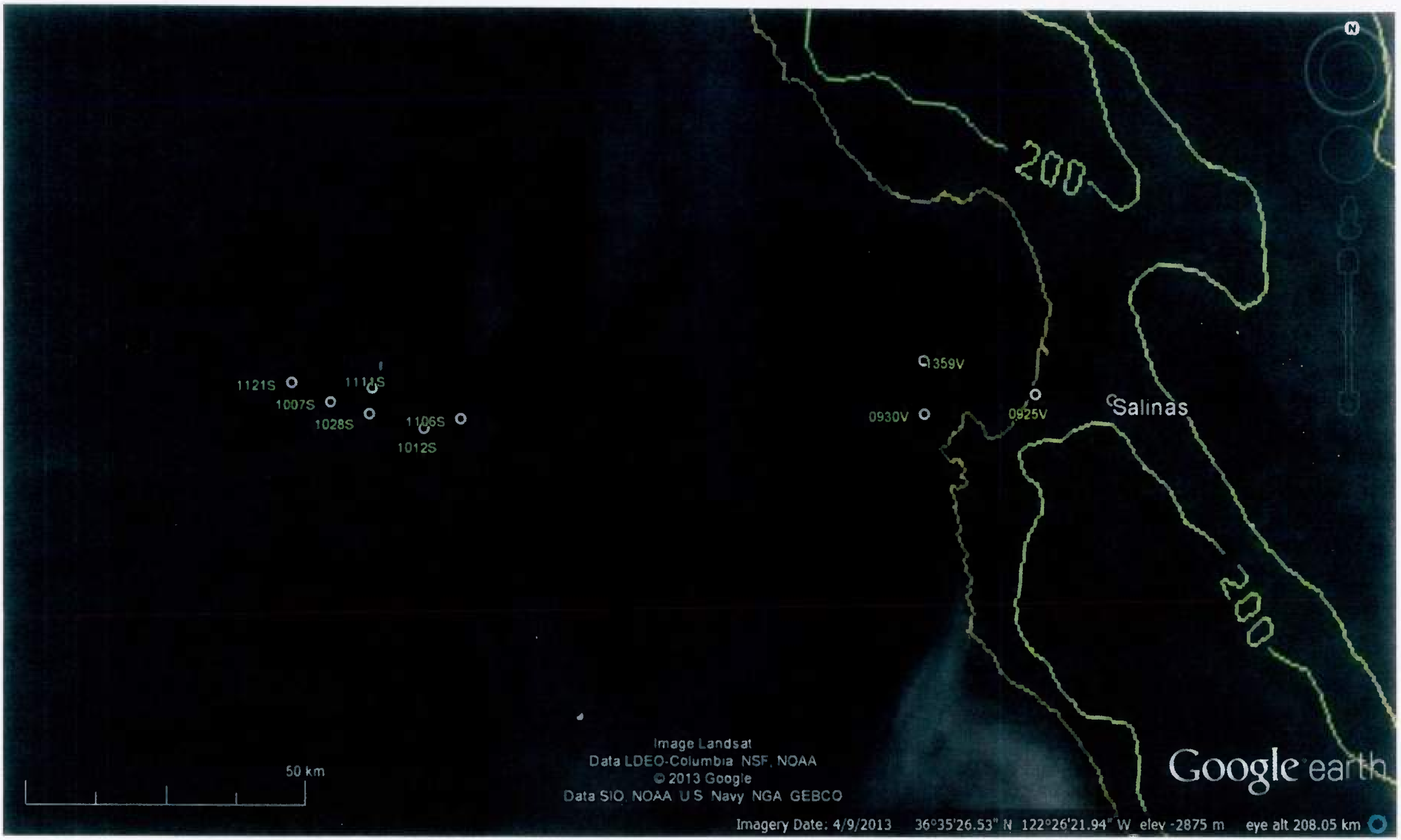
9/30/12 case study

- Process lidar data in search of organized aerosol/wind structures below the Twin Otter flight path
- Process Twin Otter “CABIN” data for time series of u, v, w, q, and Θ.
- Process CTV data for u,v,w,q and Θ.
- Match up times and then features from the TODWL and CABIN data sets near flight level.
- Match up times and features from TODWL and CTV at CTV cruise levels.

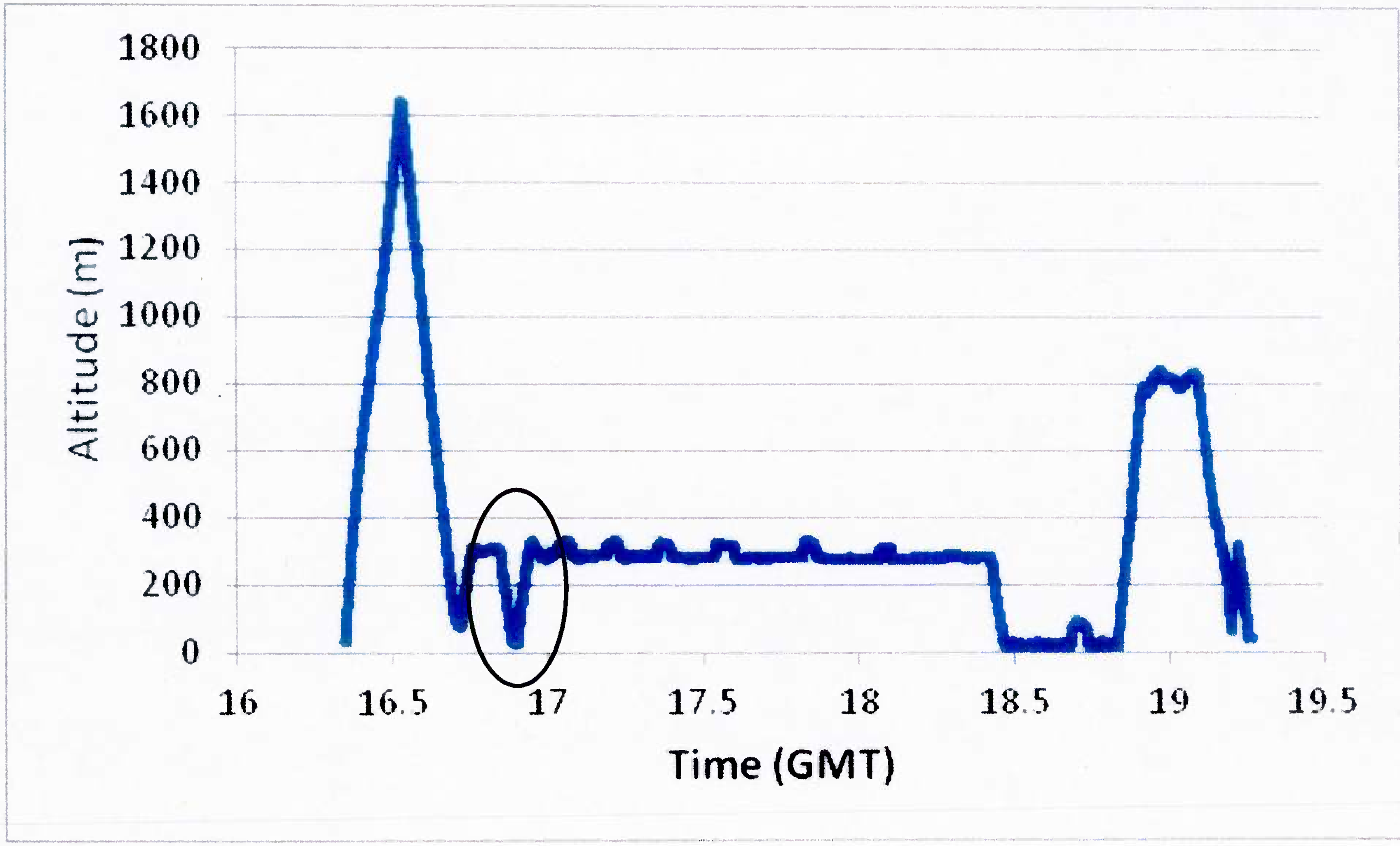
Flight path


156
68
© 2013 Google
Data LDEO-Columbia, NSF, NOAA
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2013 TerraMetrics
Google earth
36°39'35.85" N 122°34'12.54" W elev -2601 m eye alt 128.43 km

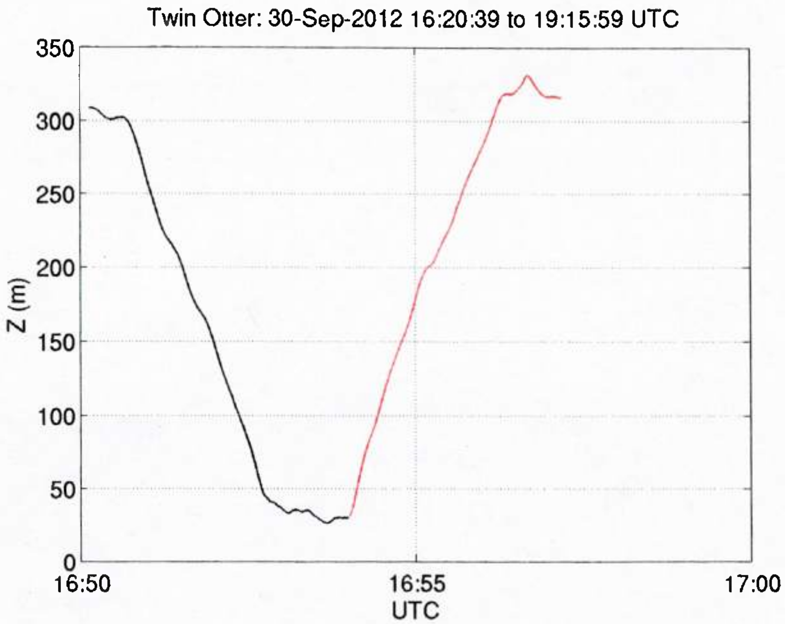
Time (LST) and Location of CTV/Lidar Data and 1045 LST GOESW Imagery

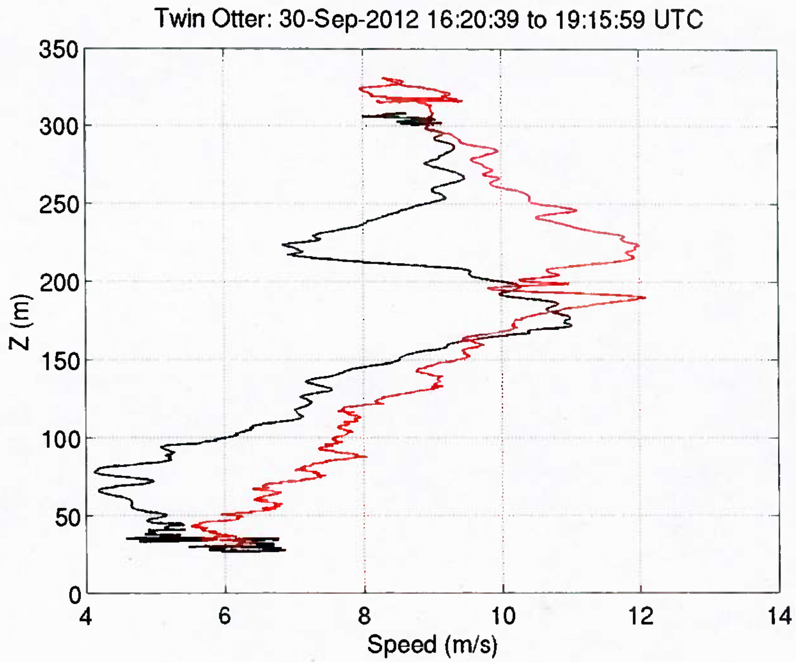


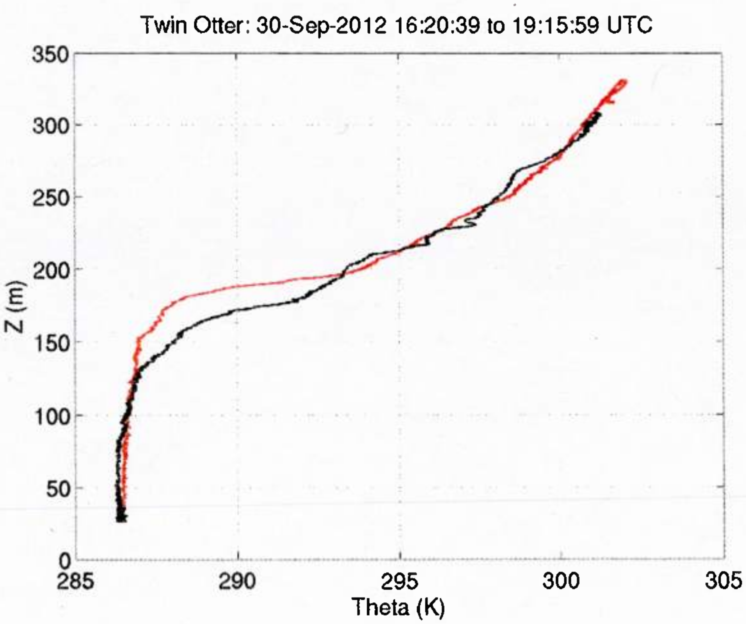
Time (LST) and Location of CTV/Lidar Data and 1145 LST GOESW Imagery

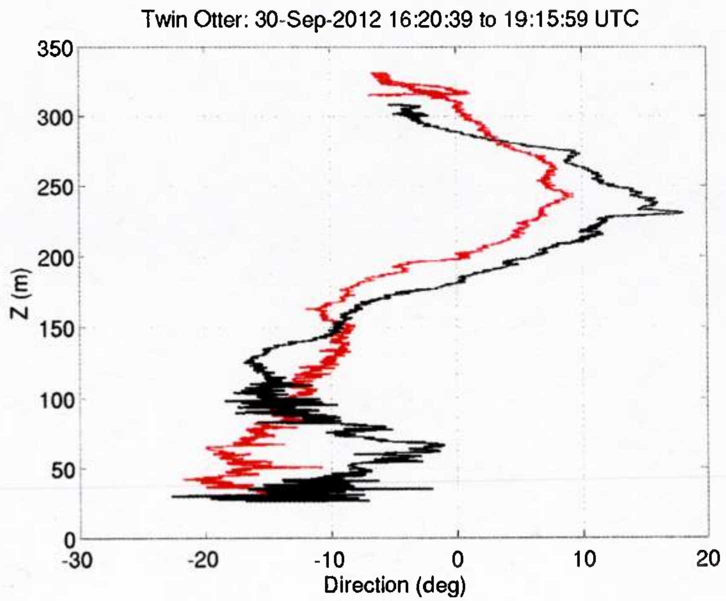


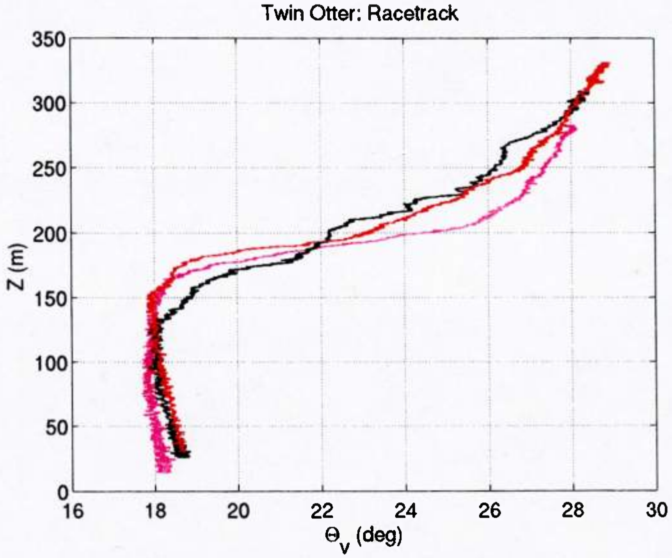
1800
1600
1400
1200
1000
800
600
400
200
0
Altitude (m)
16
16.5
17
17.5
18
18.5
19
19.5
Time (GMT)


Twin Otter: 30-Sep-2012 16:20:39 to 19:15:59 UTC
Z (m)
UTC
16:50
16:55
17:00

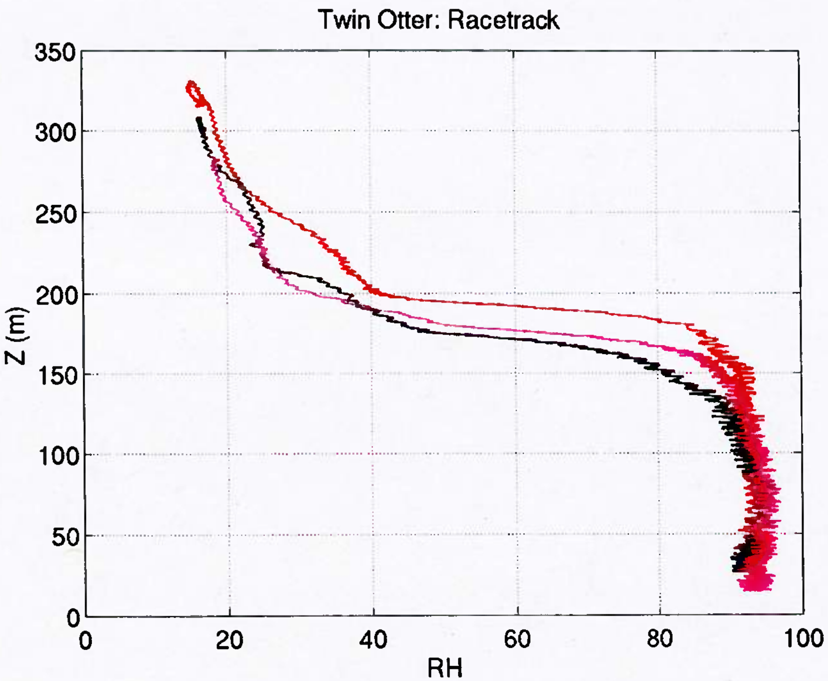

Twin Otter: 30-Sep-2012 16:20:39 to 19:15:59 UTC
Z (m)
Speed (m/s)


Twin Otter: 30-Sep-2012 16:20:39 to 19:15:59 UTC
Z (m)
Theta (K)

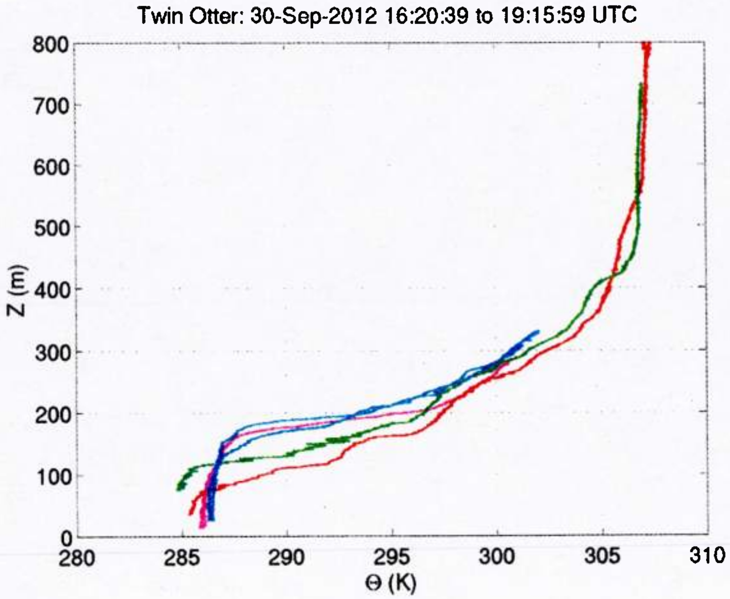

Twin Otter: 30-Sep-2012 16:20:39 to 19:15:59 UTC
Z (m)
Direction (deg)



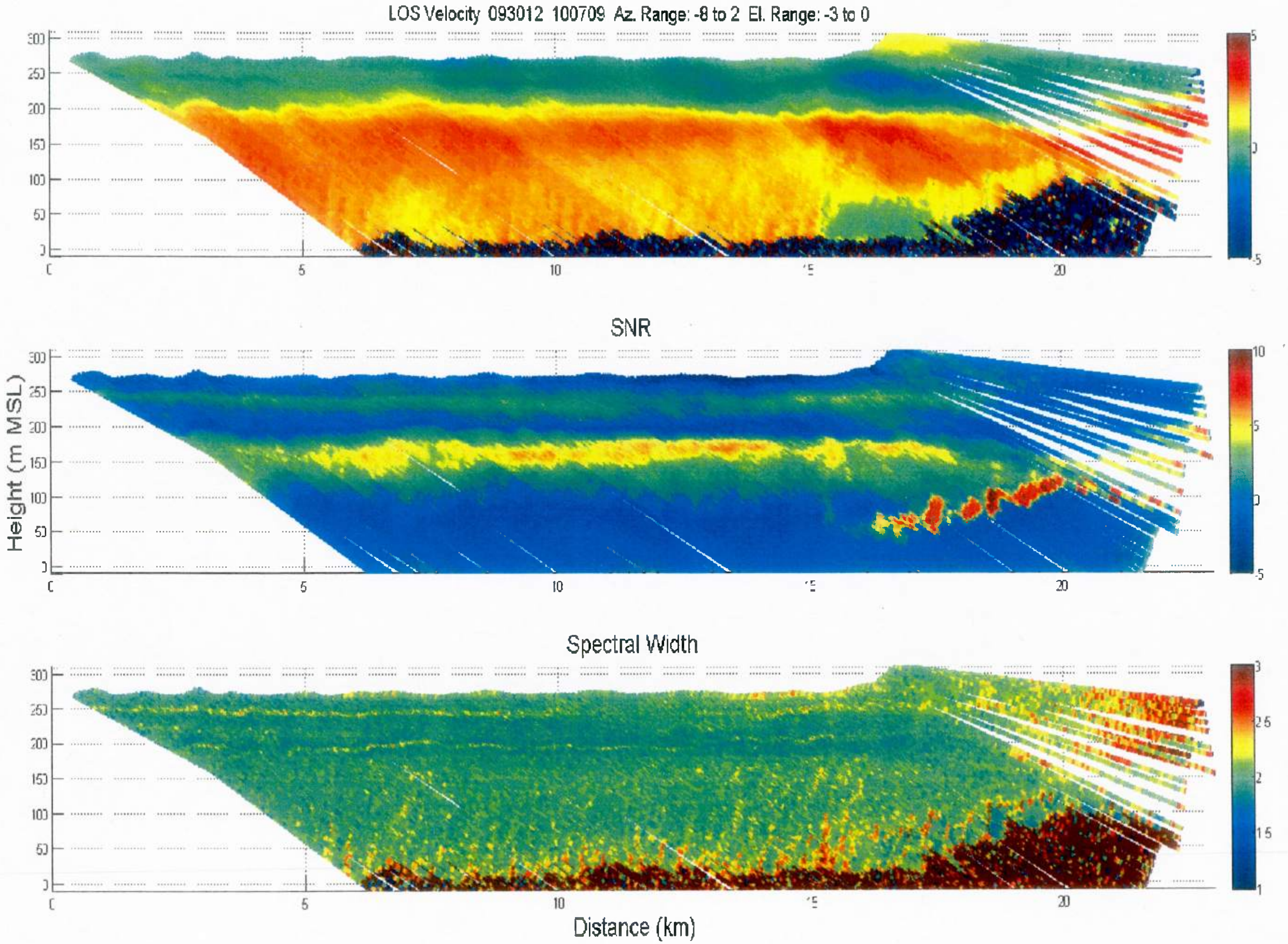
Twin Otter: Racetrack
Z (m)
Θ_v (deg)



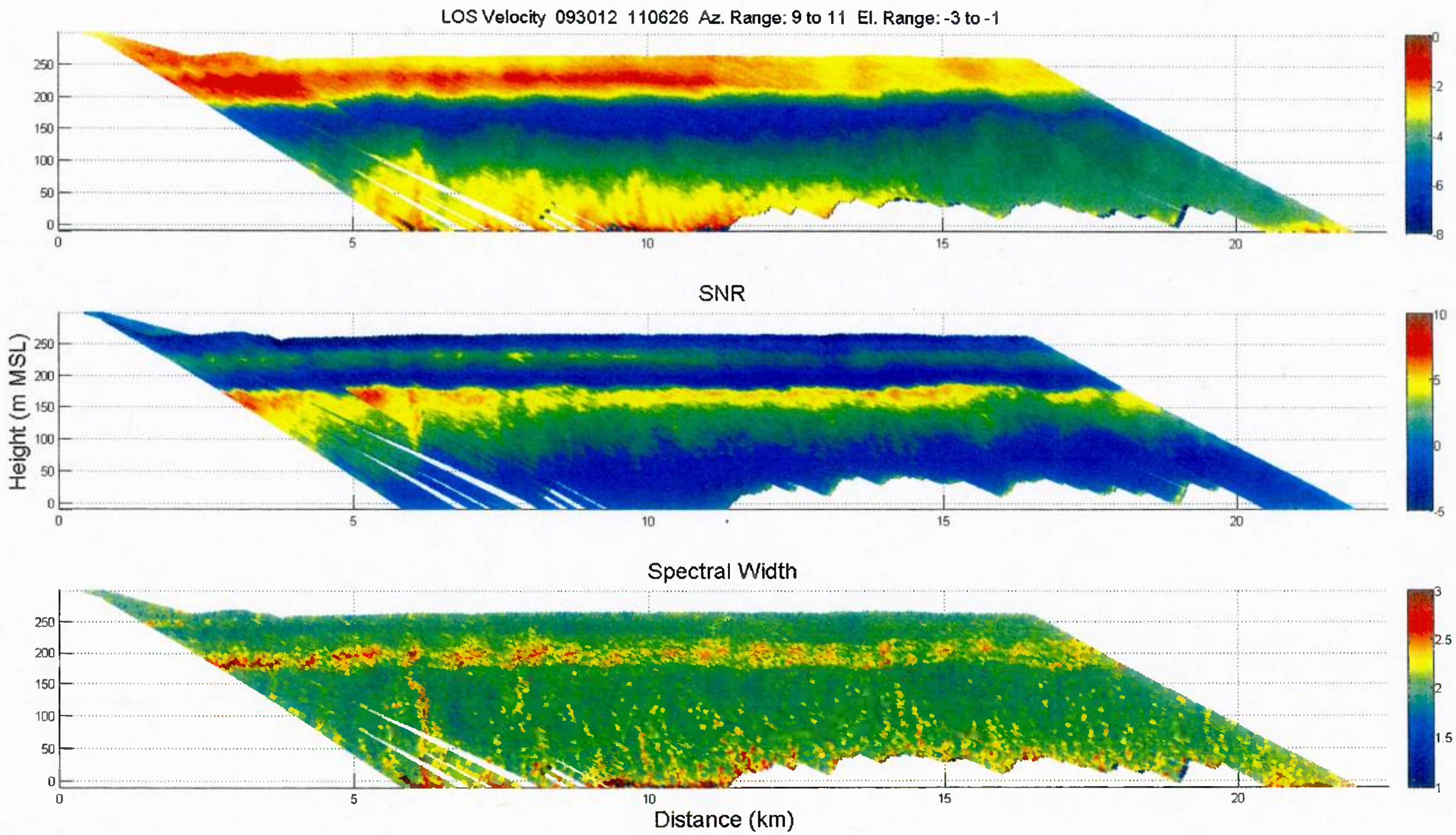
Twin Otter: Racetrack
Z (m)
RH

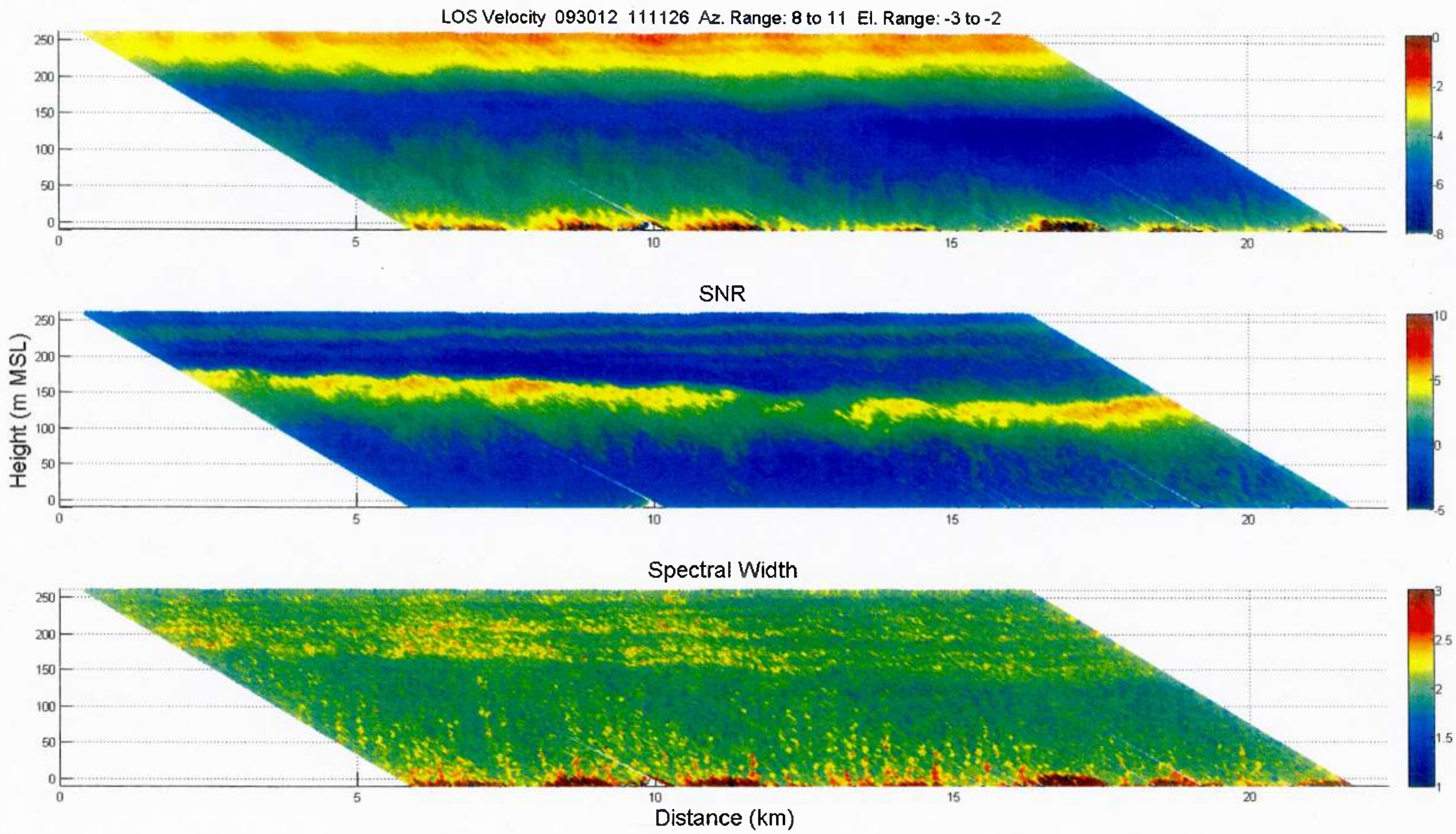


Twin Otter: 30-Sep-2012 16:20:39 to 19:15:59 UTC
Z (m)
Θ (K)

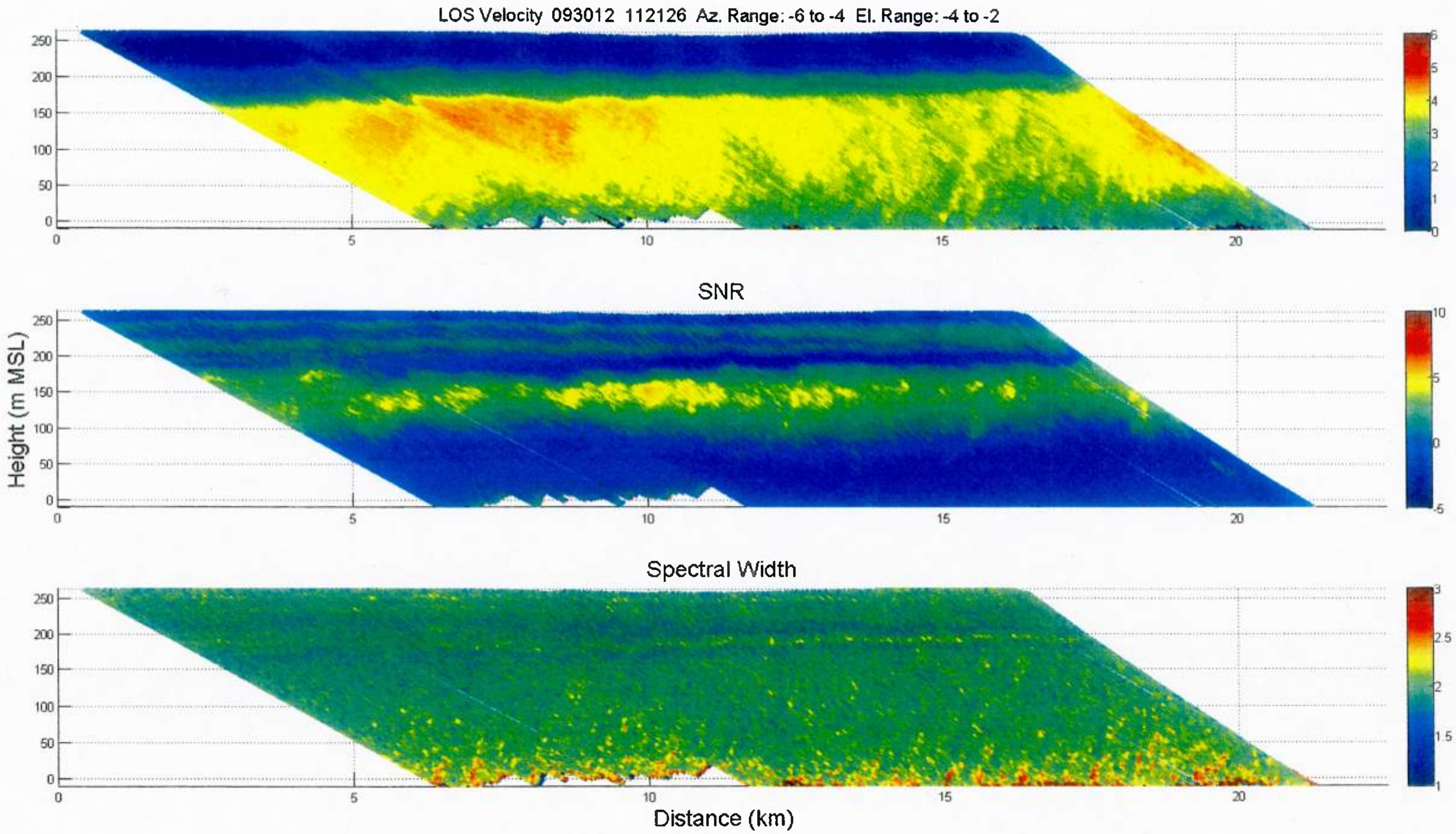


LOS Velocity 093012 100709 Az. Range: -8 to 2 El. Range: -3 to 0
SNR
Spectral Width
Height (m MSL)
Distance (km)

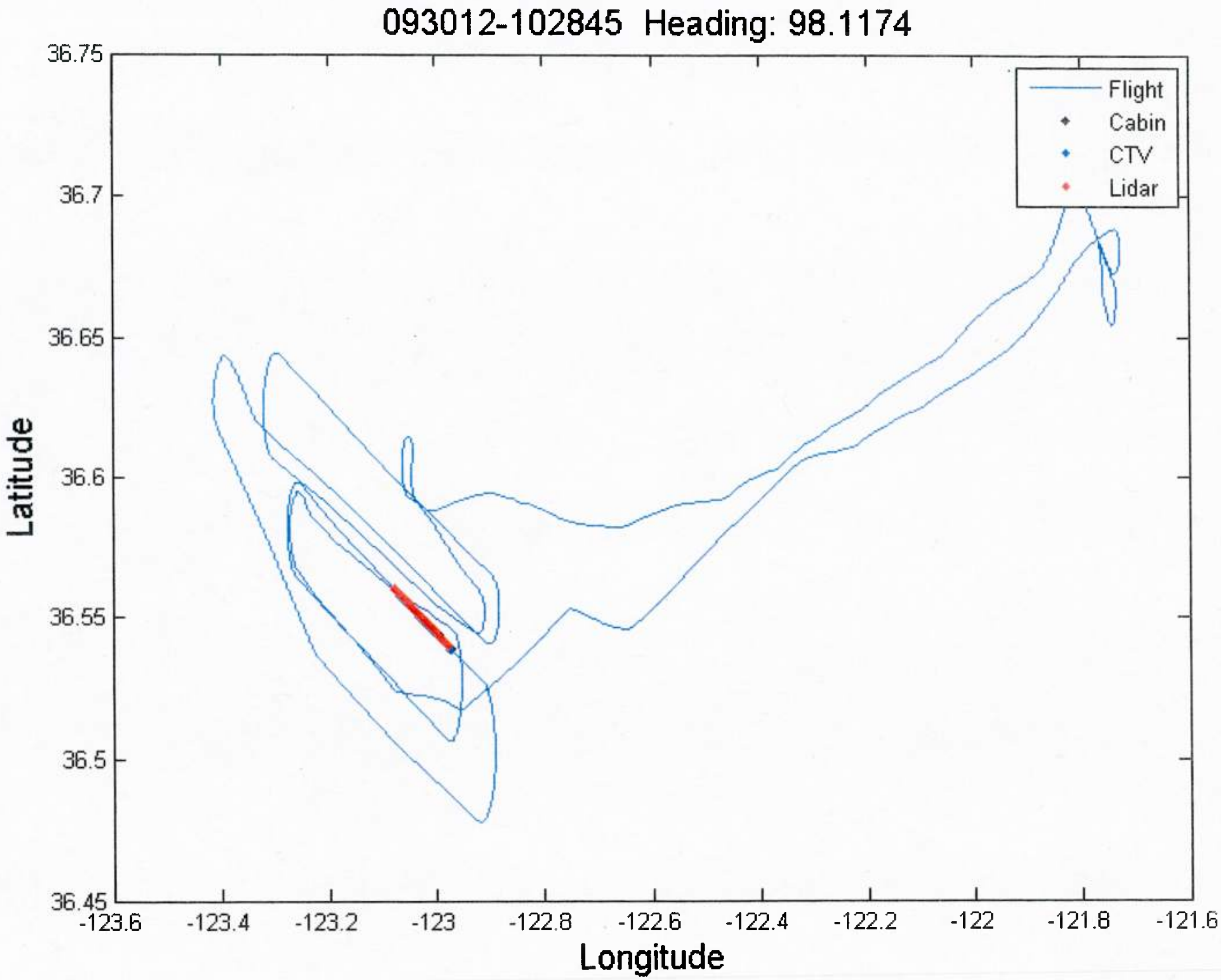

LOS Velocity 093012 110626 Az. Range: 9 to 11 El. Range: -3 to -1
SNR
Spectral Width
Height (m MSL)
Distance (km)



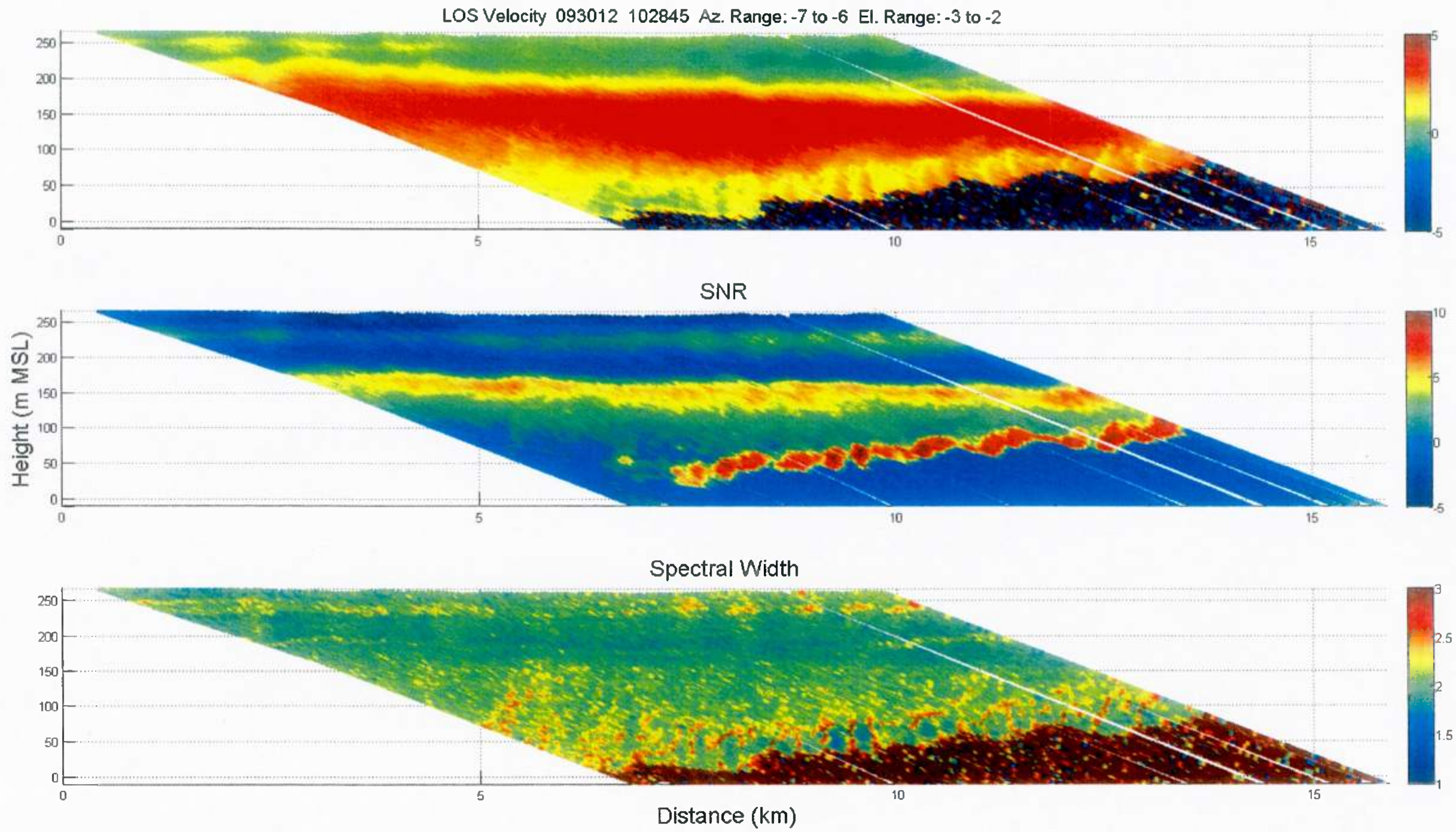
LOS Velocity 093012 111126 Az. Range: 8 to 11 El. Range: -3 to -2
SNR
Spectral Width
Height (m MSL)
Distance (km)



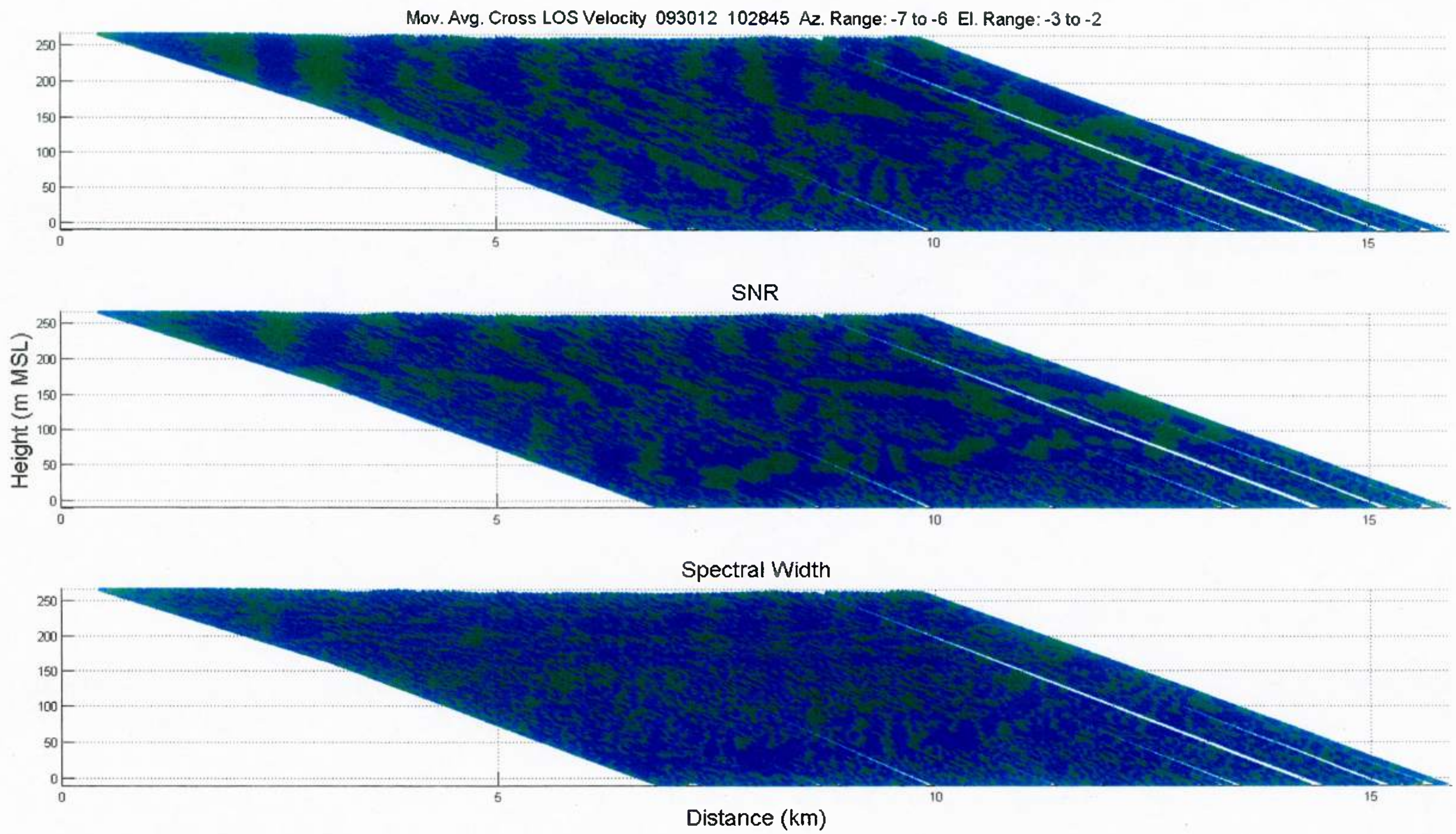
LOS Velocity 093012 112126 Az. Range: -6 to -4 El. Range: -4 to -2
SNR
Spectral Width
Height (m MSL)
Distance (km)



093012-102845 Heading: 98.1174
Flight
Cabin
CTV
Lidar
Latitude
Longitude
36.75
36.7
36.65
36.6
36.55
36.5
36.45
-123.6
-123.4
-123.2
-123
-122.8
-122.6
-122.4
-122.2
-122
-121.8
-121.6

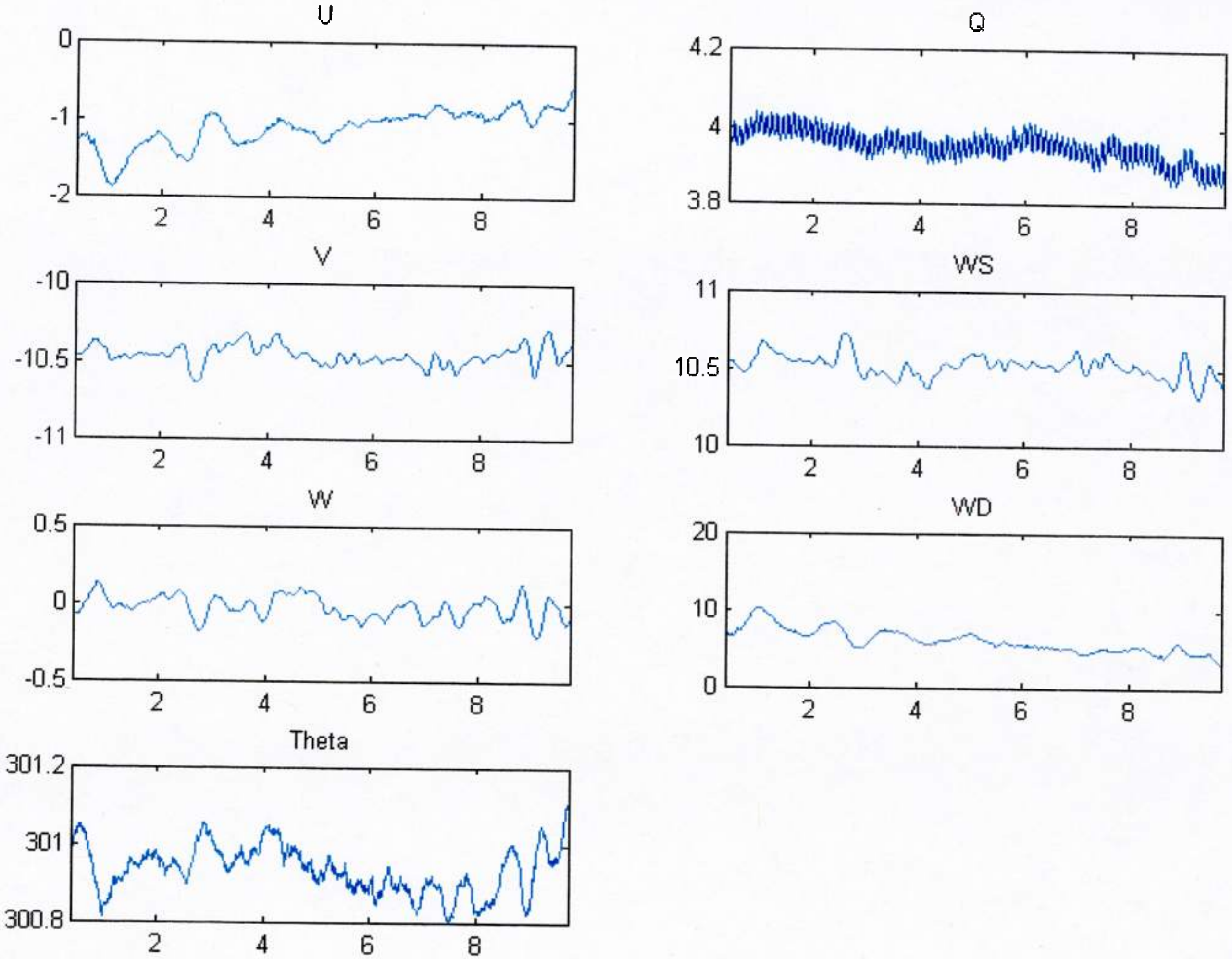


LOS Velocity 093012 102845 Az. Range: -7 to -6 El. Range: -3 to -2
SNR
Spectral Width
Height (m MSL)
Distance (km)

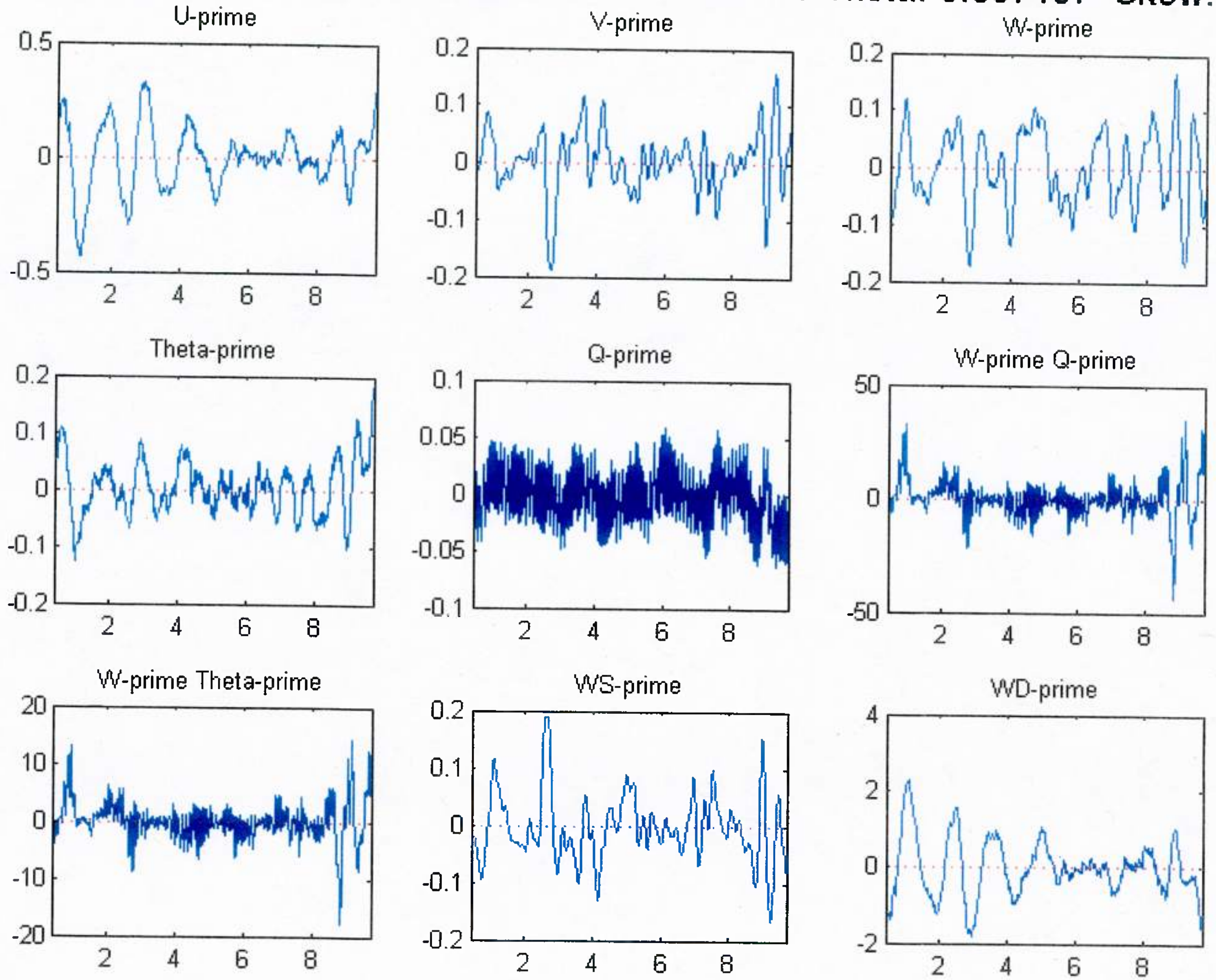


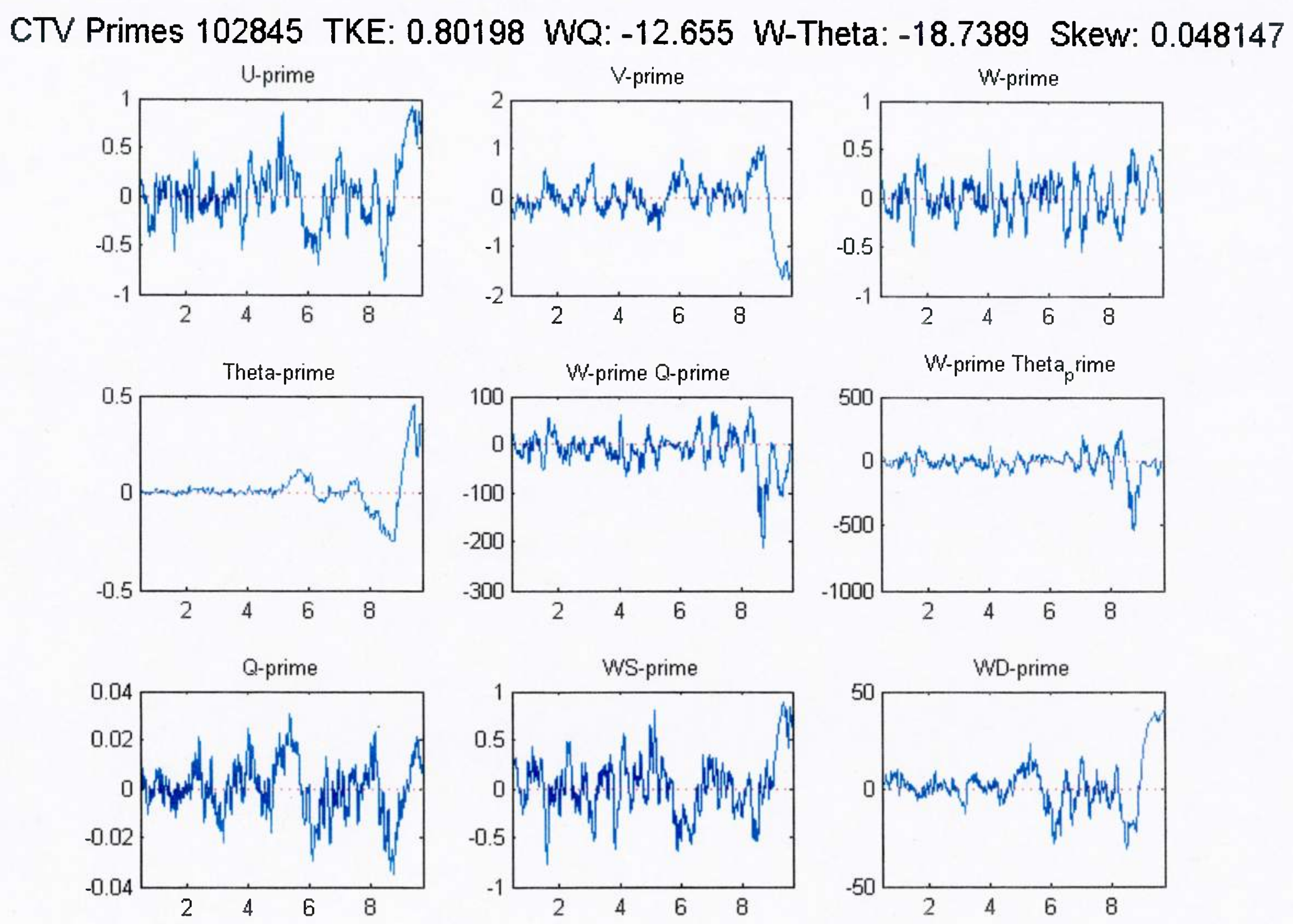
Mov. Avg. Cross LOS Velocity 093012 102845 Az. Range: -7 to -6 El. Range: -3 to -2
SNR
Spectral Width
Height (m MSL)
Distance (km)
0
5
10
15
0
50
100
150
200
250

Cabin Data 102845 TKE: 0.038198 WQ: 0.21743 W-Theta: 0.087407 Skew: -0.17748



Cabin Primes 102845 TKE: 0.038198 WQ: 0.21743 W-Theta: 0.087407 Skew: -0.1774





CTV Primes 102845 TKE: 0.80198 WQ: -12.655 W-Theta: -18.7389 Skew: 0.048147
U-prime
V-prime
W-prime
Theta-prime
W-prime Q-prime
W-prime Theta_prime
Q-prime
WS-prime
WD-prime

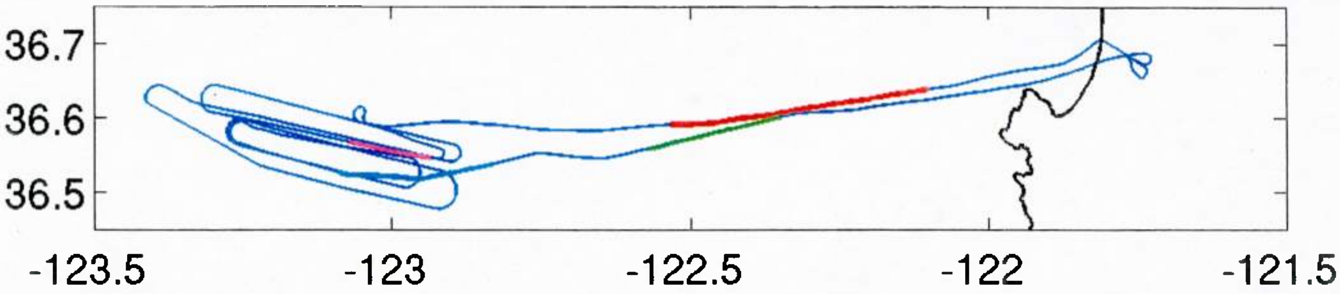
Summary of segment statistics

Flight Segment	TODWL Altitude	CTV Altitude	Heading	TKE	Sensible Heat (W)	Latent Heat (W)	Skewness
1007	284	60	94	.19	8.55	3.43	-.40
				1.92	-1.28	15.15	.90
1028	292	25	98	.04	.22	.09	-.18
				.80	-12.6	-18.7	.05
1106	286	75	294	.05	3.02	1.21	-.51
				1.1	-3.36	-1.19	-.17
1111	290	75	293	.24	1.98	.80	-.37
				.29	-.74	.55	.22
1121	288	climbing	98	.14	-1.11	-.44	.90

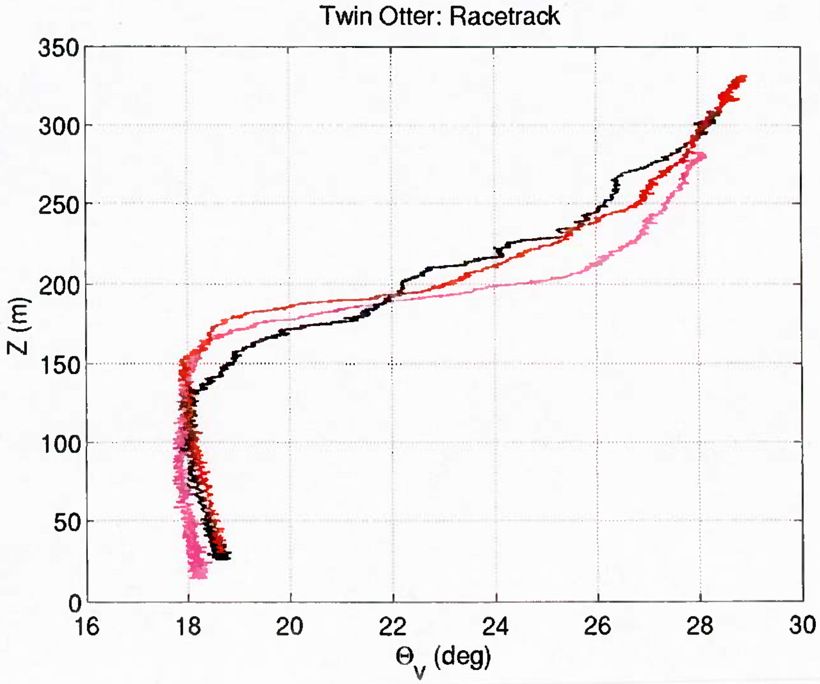
Is Double-OLE Interpretation Reasonable?

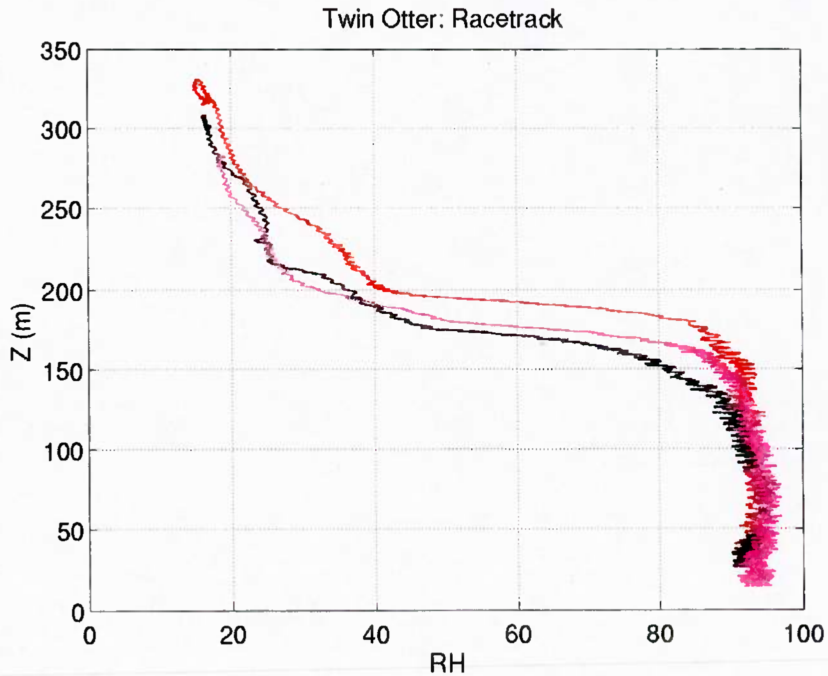
- Simplify Problem:
  - Neutral stratification
    - Shear effects only
    - Omit effect of stratification above jet
    - No surface buoyancy flux
  - Elevated, thin baroclinic layer
  - Variable K(z) (akin to MRF/YSU)
- Non-linear stability model
- Interacting triads

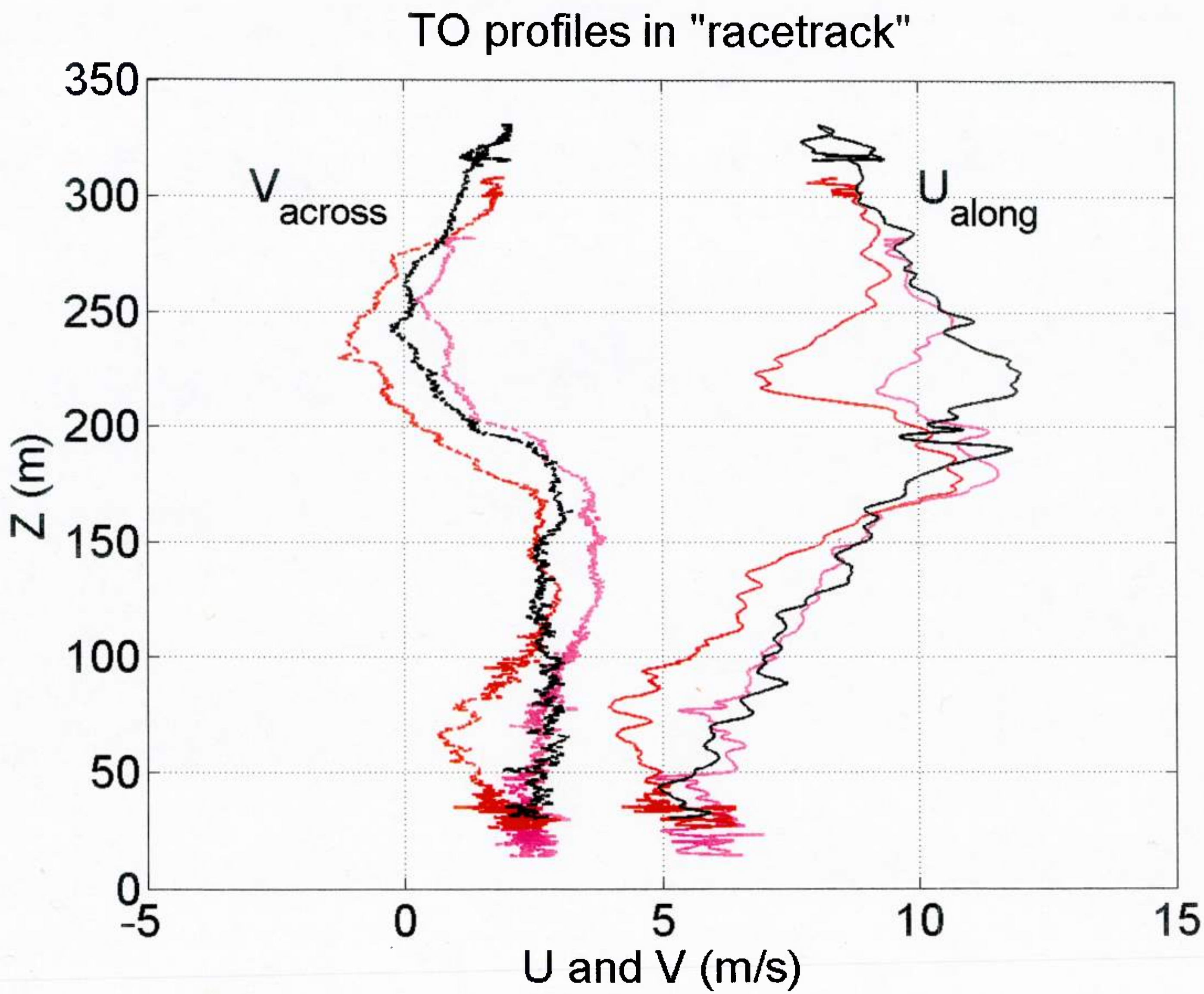
Twin Otter: 30-Sep-2012 16:20:39 to 19:15:59 UTC



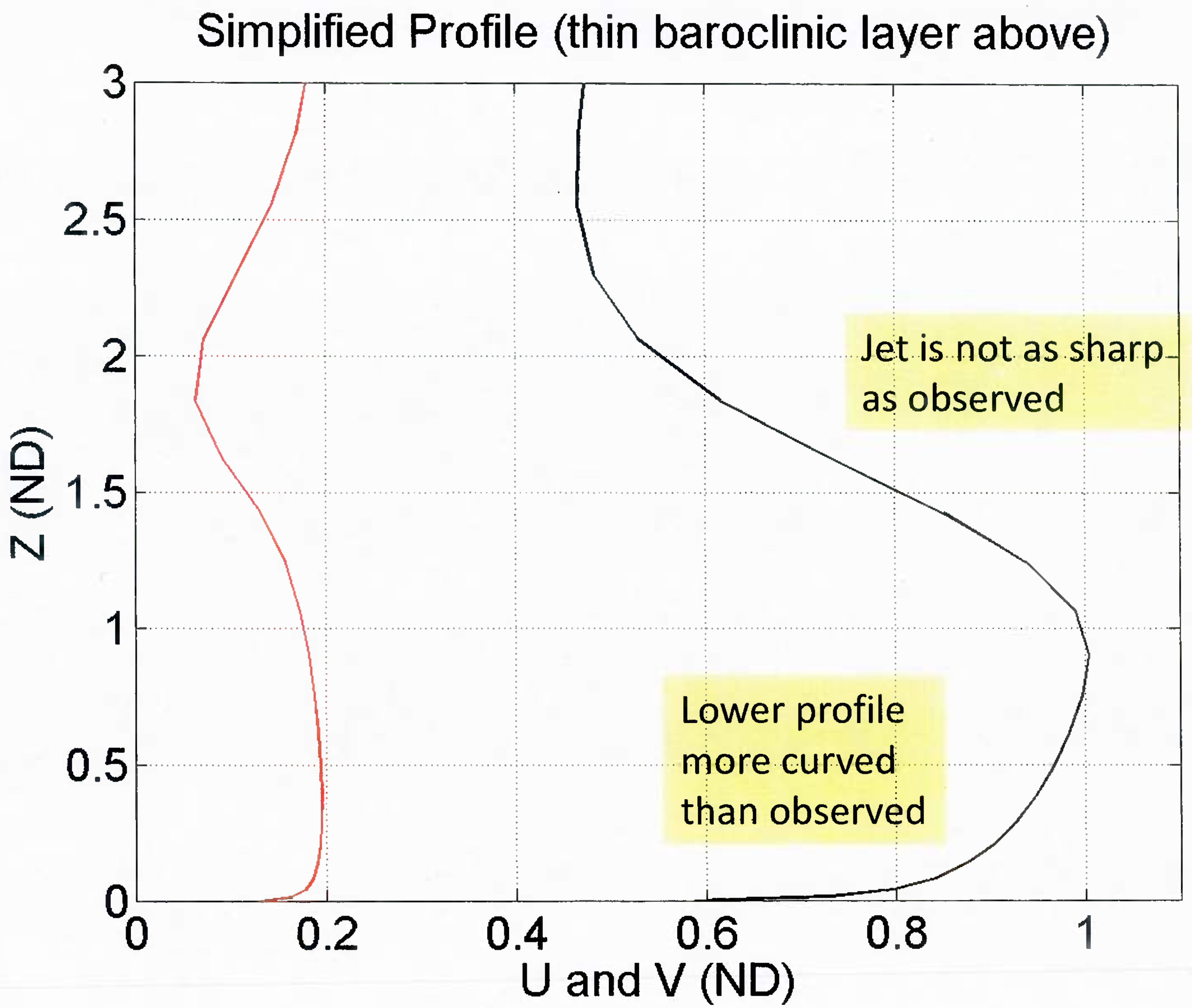
Mean wind at flight level is generally from the north

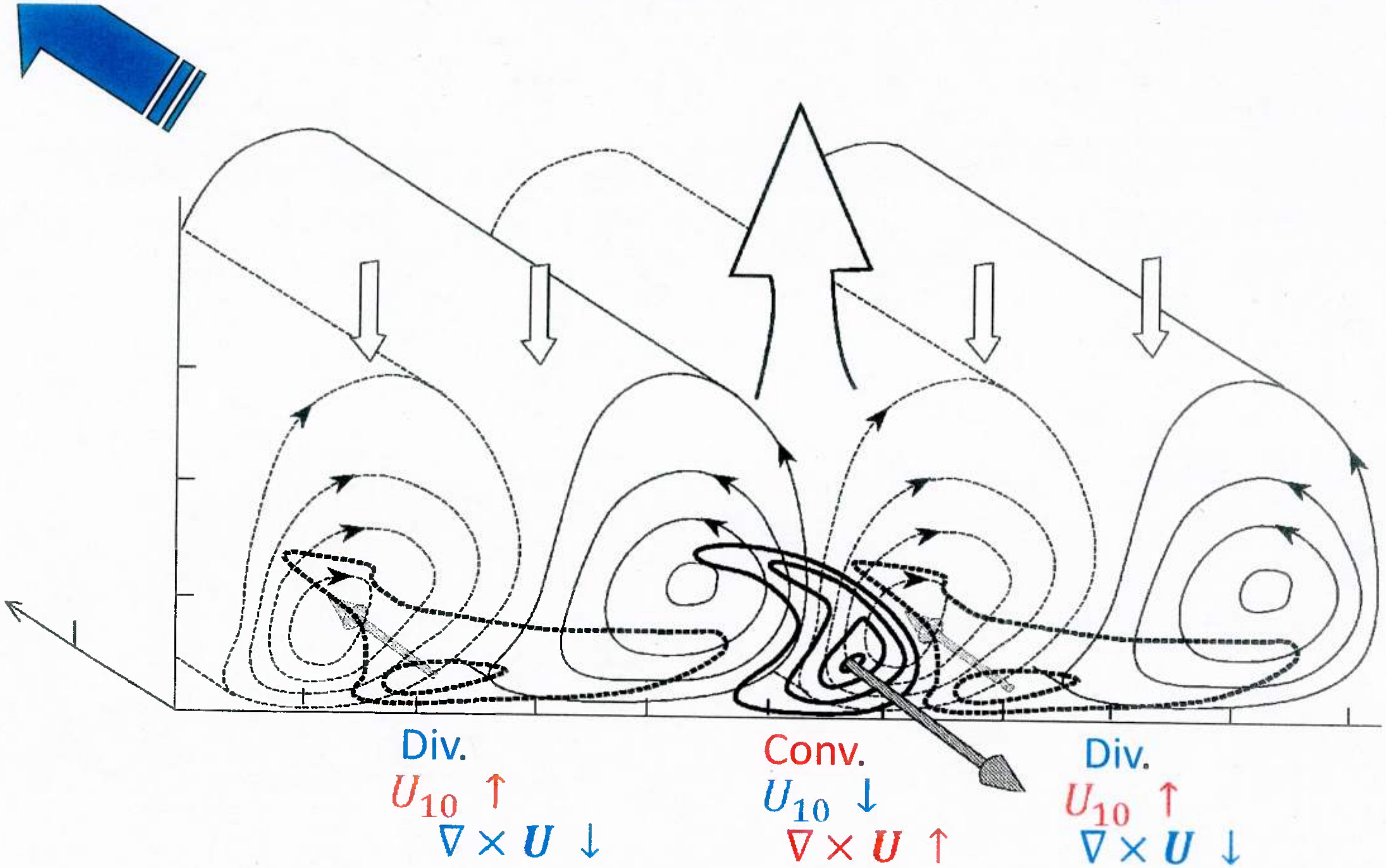






TO profiles in "racetrack"
V_{across}
U_{along}
Z (m)
U and V (m/s)
350
300
250
200
150
100
50
0
-5
0
5
10
15


Simplified Profile (thin baroclinic layer above)
Z (ND)
U and V (ND)
0
0.5
1
1.5
2
2.5
3
0
0.2
0.4
0.6
0.8
1
Jet is not as sharp as observed
Lower profile more curved than observed

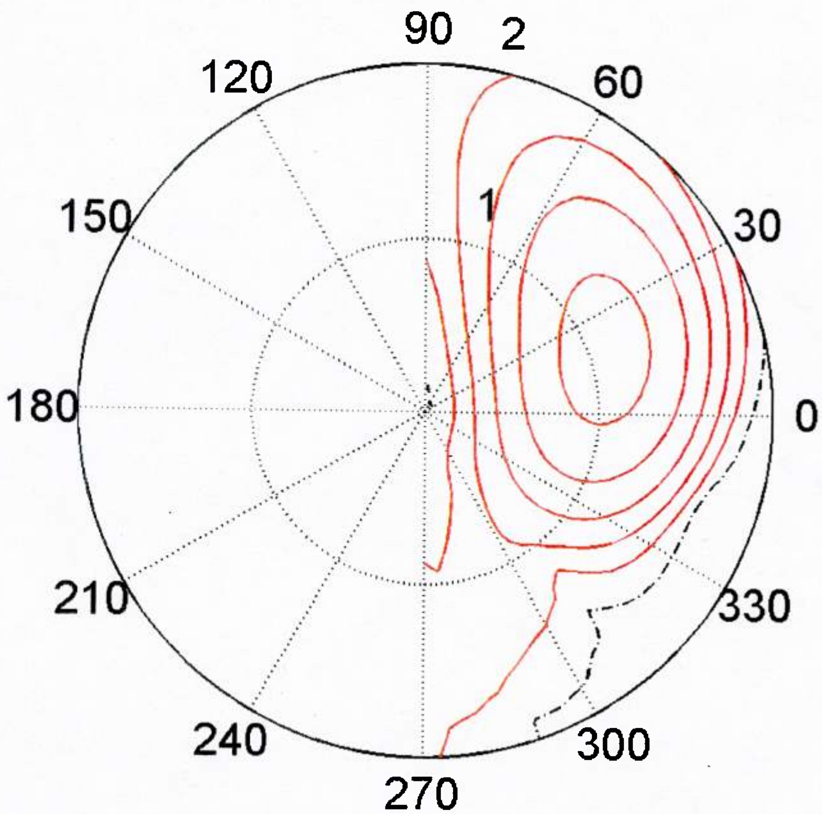


Wavelength: Larger-scale structures ~ 1.5 to 2.5 km
Smaller-scale structures ~ 300 to 700 m

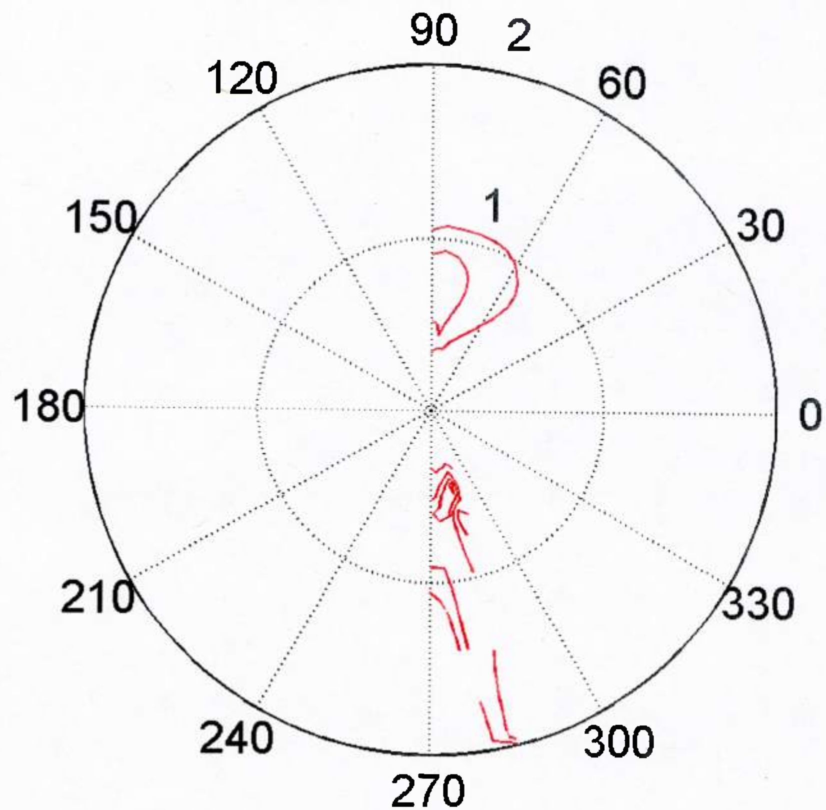
Along-roll velocity Perturbations: +/- 20-25 %
Note; largest near surface

Orientation: Typically aligned along shear

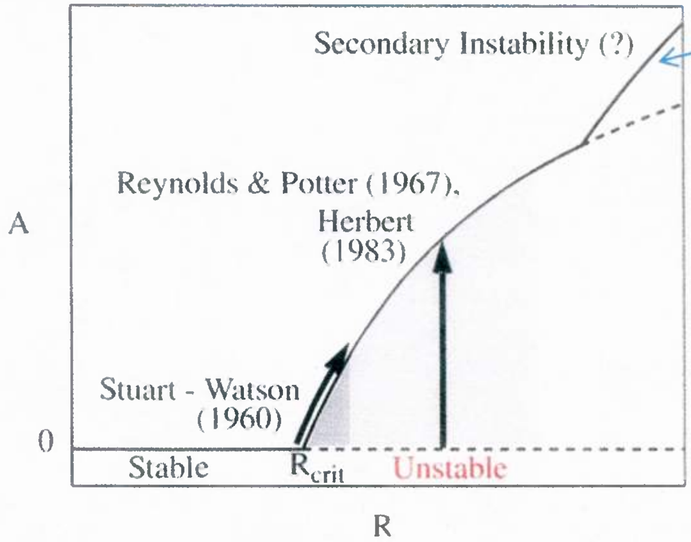
Dominant mode



Secondary mode associated with above-jet layer



Single-Wave Roll Theory
Nonlinear Stability



Multi-wave theory

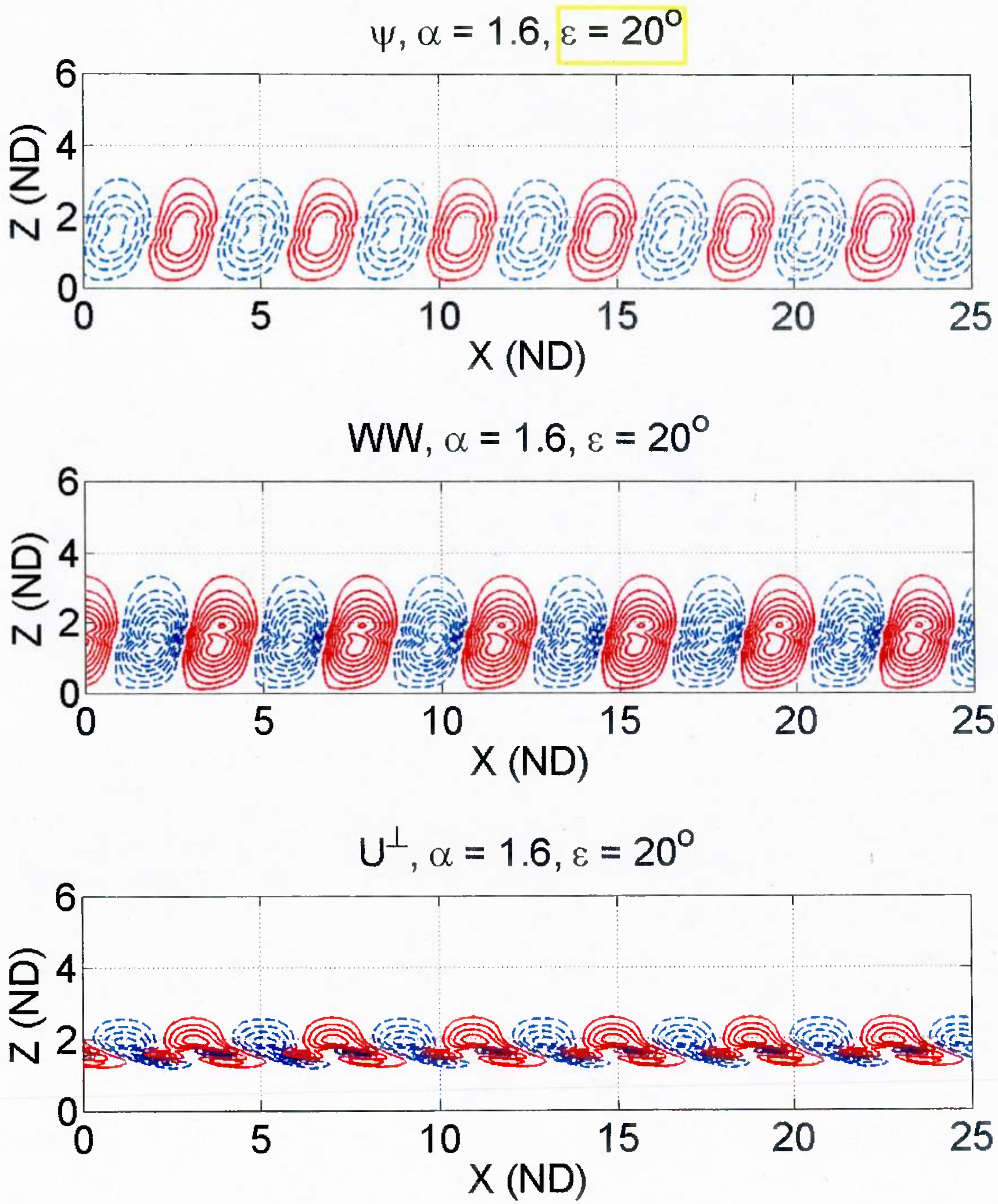
$$\lambda = a + i\omega = \frac{1}{A}\frac{dA}{dt} + i\frac{d\eta}{dt} = \lambda_0 + A^2\lambda_1 + A^4\lambda_2 + \cdots$$

$$\underset{\sim}{q} = 2real\left[\sum_{n=0}^{\infty} A^n e^{in(\alpha x - \omega t)} \sum_{m=0}^{\infty} A^{2m} \underset{\sim}{q}_{nm}(z)\right]$$

- "Stretch" eigenvalue, λ_0, in powers of nonlinear amplitude, *A(t)*.
- Expand eigenfunction, q_{10}, in harmonics of fundamental wavenumber, α, and forced modifications
  - Forced fundamental modifications are orthogonal to linear mode
  - Determine Landau Coefficients (the λ_i)
- Estimate equilibrium Amplitude ($dA/dt = 0$) & structure, $\boldsymbol{q} = [u,v,w,T]^T$

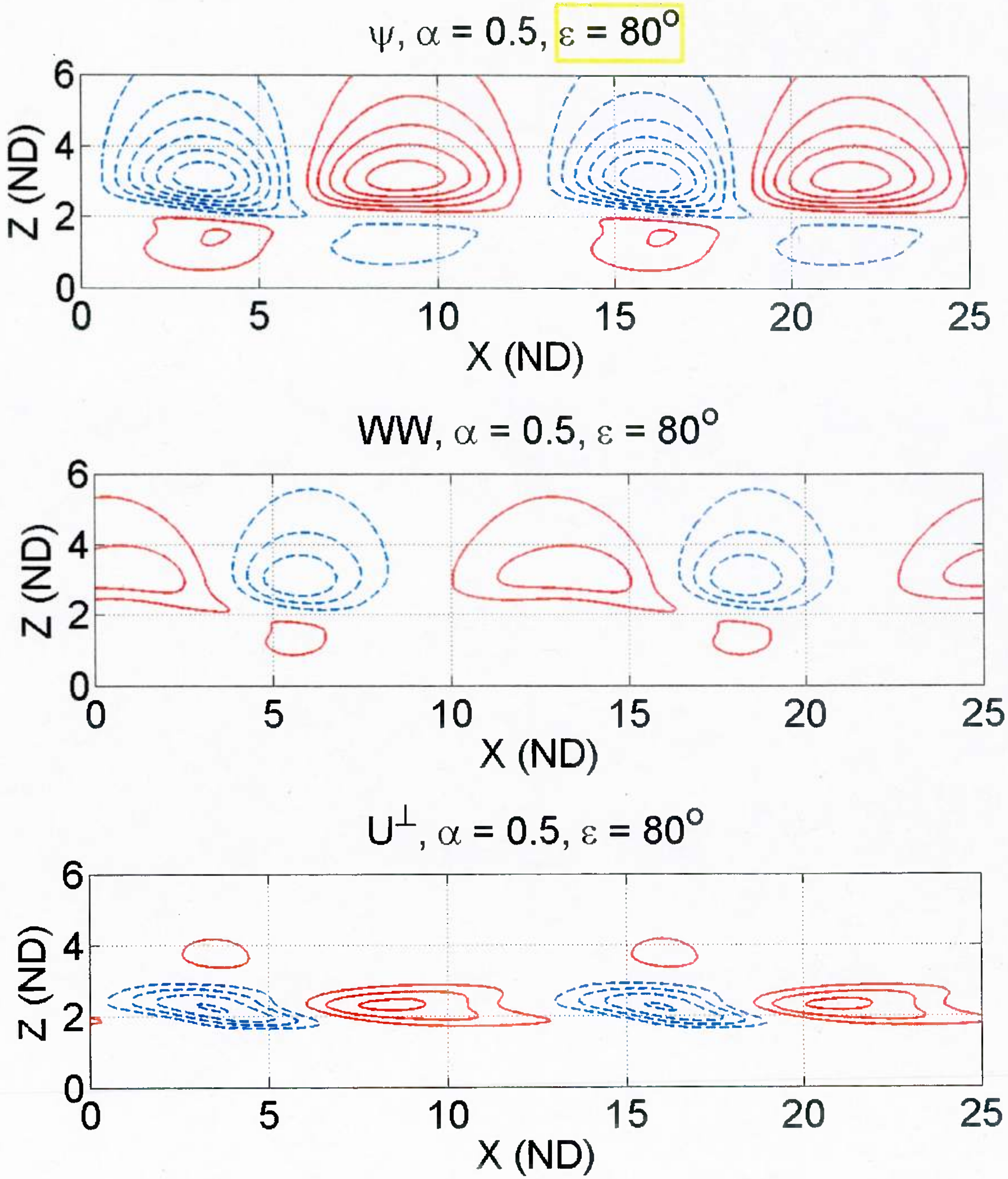
Primary Mode

- Mostly in the sub-jet layer
- Along-roll velocity strongest near jet as compared to std. rolls
- Oriented at large angle to dominant rolls



Weaker, secondary mode

- Similar to STD rolls, but based on jet top
- Along-roll velocity max near jet
- Oriented at large angle to dominant rolls



Resonant Triad Interaction Between OLE

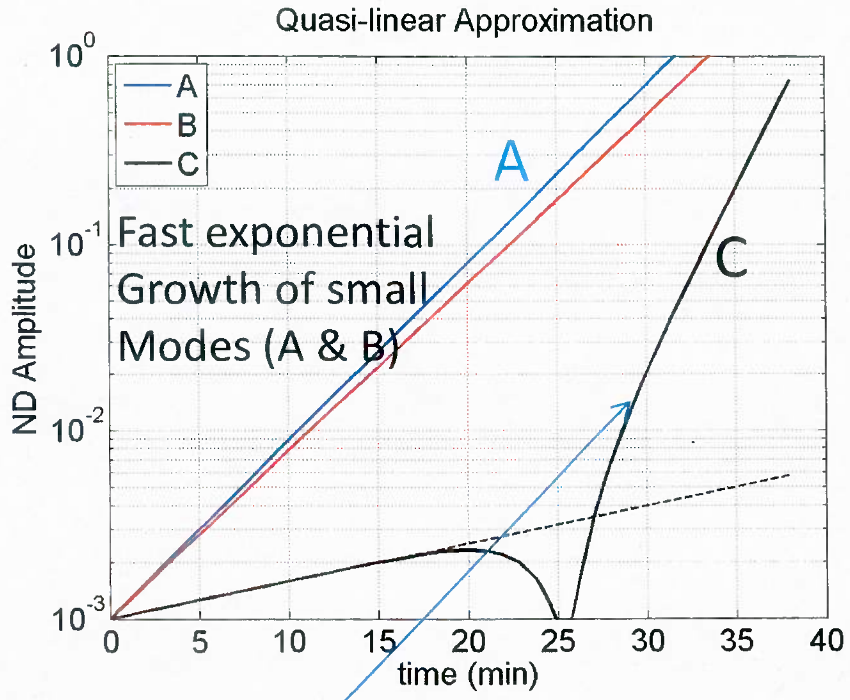
- $\alpha = \beta + \gamma$ (mode A, mode B, mode C) wavenumber relationship
- Require at least one wavenumber at fastest growing mode (A)
- Exchange of energy between OLE modes
- Often energizes weak modes
- At present, require co-linear modes (can be relaxed)

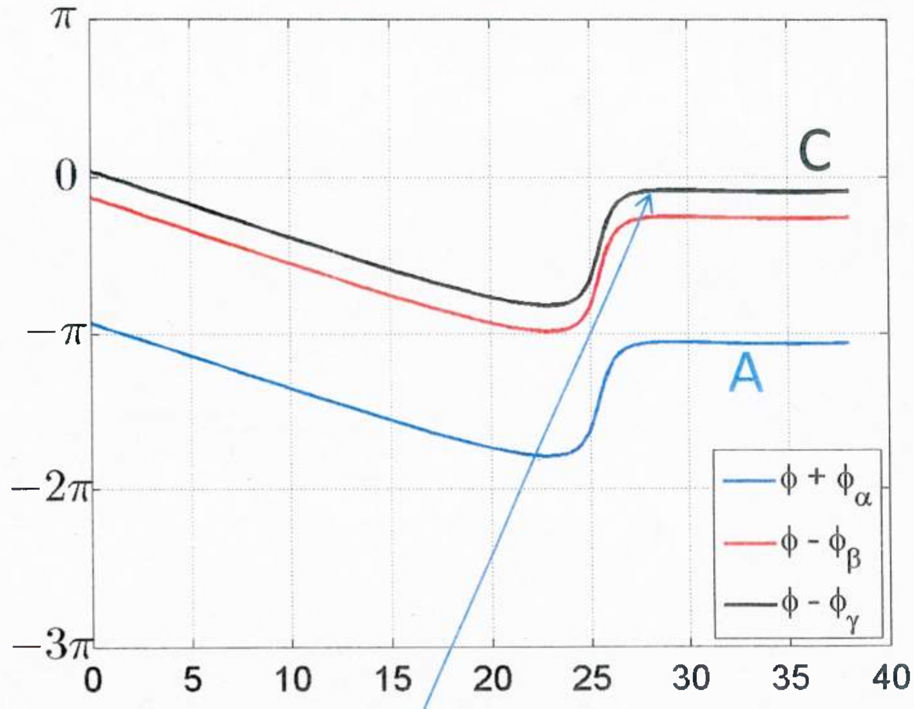
Truncated Model
Amplitude (real) and Phase (imaginary)

- $\frac{1}{A}\frac{dA}{dt} - i\frac{d\theta_A}{dt} = \boxed{a_0} + \boxed{a_1 \frac{BC}{A} e^{i\phi}} + [\boxed{a_2} A^2 + a_3 B^2 + a_4 C^2]$
- $\frac{1}{B}\frac{dB}{dt} - i\frac{d\theta_B}{dt} = \boxed{b_0} + \boxed{b_1 \frac{AC}{B} e^{-i\phi}} + [b_2 A^2 + \boxed{b_3} B^2 + b_4 C^2]$
- $\frac{1}{C}\frac{dC}{dt} - i\frac{d\theta_C}{dt} = \boxed{c_0} + \boxed{c_1 \frac{AB}{C} e^{-i\phi}} + [c_2 A^2 + c_3 B^2 + \boxed{c_4} C^2]$
- $\phi = \theta_A - \theta_B - \theta_C$ (Wave phase imbalance)
- $\alpha = \beta + \gamma$ (resonant triad wavenumbers)

- The a_i, b_i, c_i are complex, generalized Landau coefficients, calculated via an orthogonalization assumption (nonlinear wave-wave & wave-mean flow interactions)
- <u>Highest-order</u> (bracketed) terms <u>force equilibrium</u>; dominated by single-wave contributions (a_2A^2, b_3B^2, c_4C^2)
- Lower-order phase coupling allows inter-scale energy transfer, ENHANCES GROWTH RATE OF SLOWEST-GROWING MODE, ESPECIALLY DURING QUASI-LINEAR PHASE

How is the slowly-growing mode energized? Examine quasi-linear, early-time behavior





Accelerated growth of slow mode (C)

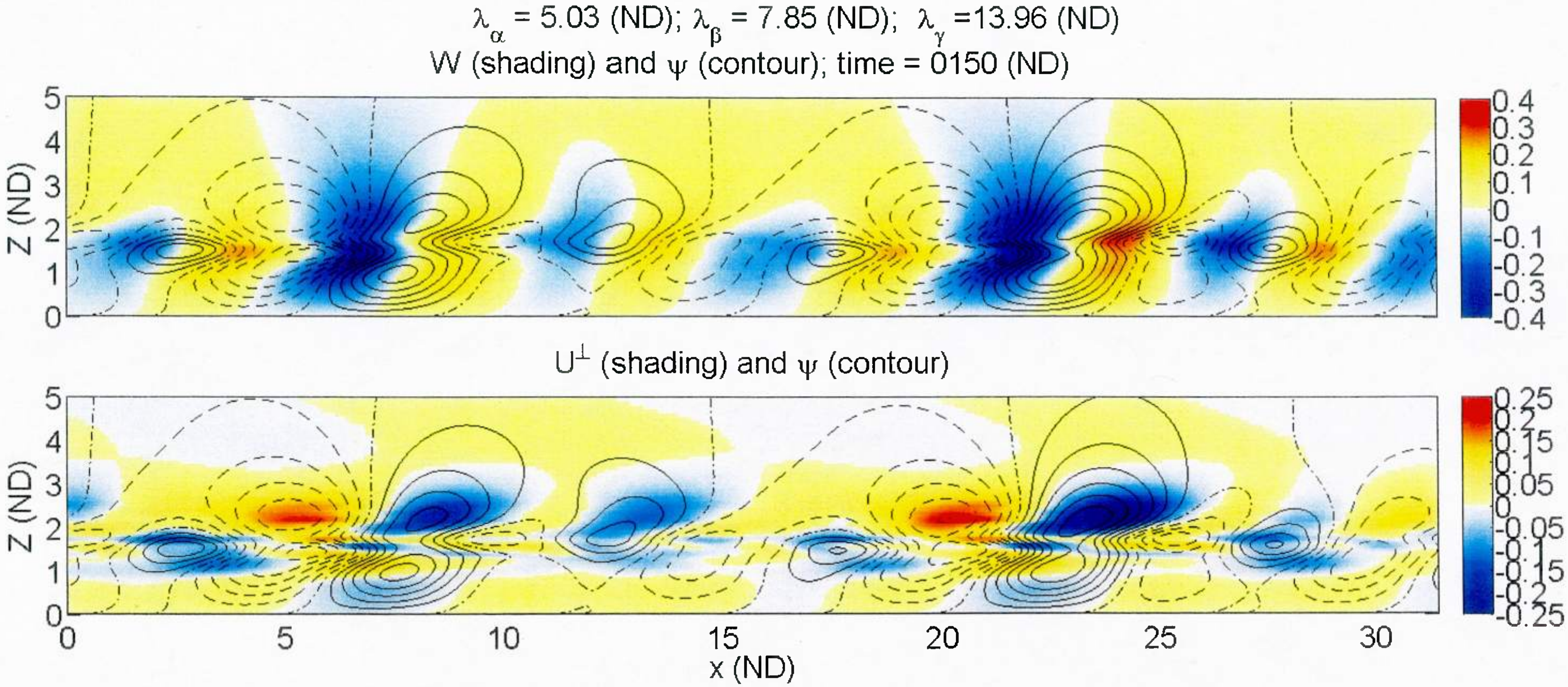
Starts when ($\phi - \phi_{c1}$) → $2\pi n$

Phase Imbalance:

$$\phi = \theta_A - \theta_B + \theta_C$$

QL Landau Coefficient:

$$c_1 = |c_1|\, e^{i\phi_\gamma}$$



λ_α = 5.03 (ND); λ_β = 7.85 (ND); λ_γ =13.96 (ND)
W (shading) and ψ (contour); time = 0150 (ND)
Z (ND)
$U^\perp$ (shading) and ψ (contour)
Z (ND)
x (ND)

Sub-Summary

- **IT APPEARS THAT A PBL JET CAN INDUCE "STACKED" OLE**
  - Caveat: test case is neutral stratification
    - In model, but examine neutral first
- **CO-LINEAR OLE TRIADS CAN GENERATE COMPLEX STRUCTURE**
- **THERE IS A WEAKER, LARGER-SCALE, OBLIQUE ABOVE-JET MODE**
  - Can it be energized by nonlinear triad mechanism?
- Future work
  - Modify triad code for non-co-linear OLE
  - Include stratification and thermal wind effects on OLE

Revise and Add to Overall Summary

- EDMF-type schemes attempt to capture non-local contributions to PBL fluxes
  - Implicitly assumes such transport is due to narrow, skewed updrafts
  - Quite unstable stratification
- OLE rolls are very common
  - low skewness
  - Likely significant flux contributions
  - Near-neutral to moderately unstable stratificaton
    - Possible also slightly stable?

Extra Slides

Truncated 3-Mode Roll Solutions

$$q_\alpha = Aq_{0,\alpha} + \boxed{BCq_{1,\alpha}e^{i\phi}} + A[A^2q_{2,\alpha} + B^2q_{3,\alpha} + C^2q_{4,\alpha}] + A^2q_{20,\alpha} + A^3q_{30,\alpha}$$

$$q_\beta = Bq_{0,\beta} + \boxed{ACq_{1,\beta}e^{-i\phi}} + B[A^2q_{2,\beta} + B^2q_{3,\beta} + C^2q_{4,\beta}] + B^2q_{20,\beta} + B^3q_{30,\beta}$$

$$q_\gamma = Cq_{0,\gamma} + \boxed{ABq_{1,\gamma}e^{-i\phi}} + C[A^2q_{2,\gamma} + B^2q_{3,\gamma} + C^2q_{4,\gamma}] + C^2q_{20,\gamma} + C^3q_{30,\gamma}$$

$$\phi = \theta_A - \theta_B - \theta_C$$

- **YELLOW**: contributions from single-wave theory; e.g. $q_{2,\alpha} = q_{11,\alpha}$.
- **BLUE**: new wave-wave & wave-mean flow interaction contributions.
- **RED:** Low-order phase-coupling terms.
- Also: mean-flow modifications due to each wave.

Standard Non-Linear Single-Wave PBL Roll Model

Table 5.1 Contributions to the nonlinear perturbation up to the fifth Landau Coefficient

Order	Landau	q_0	q_1	q_2	q_3	q_4	q_5	q_6	q_7	q_8	q_9	q_{10}	q_{11}
1		MF											
A	λ_0		q_{10}										
A^2		q_{01}		q_{20}									
A^3	λ_1		q_{11}		q_{30}								
A^4		q_{02}		q_{21}		q_{40}							
A^5	λ_2		q_{12}		q_{31}		q_{50}						
A^6		q_{03}		q_{22}		q_{41}		q_{60}					
A^7	λ_3		q_{13}		q_{32}		q_{51}		q_{70}				
A^8		q_{04}		q_{23}		q_{42}		q_{61}		q_{80}			
A^9	λ_4		q_{14}		q_{33}		q_{52}		q_{71}		q_{90}		
A^{10}		q_{05}		q_{24}		q_{43}		q_{62}		q_{81}		q_{100}	
A^{11}	λ_5		q_{15}		q_{34}		q_{53}		q_{72}		q_{91}		q_{110}

Truncated Contributions to Multi-Wave Roll Model

$$\mathbf{q} = [u, v, w, T]^T$$

To 1st Nonlinear Landau Term:

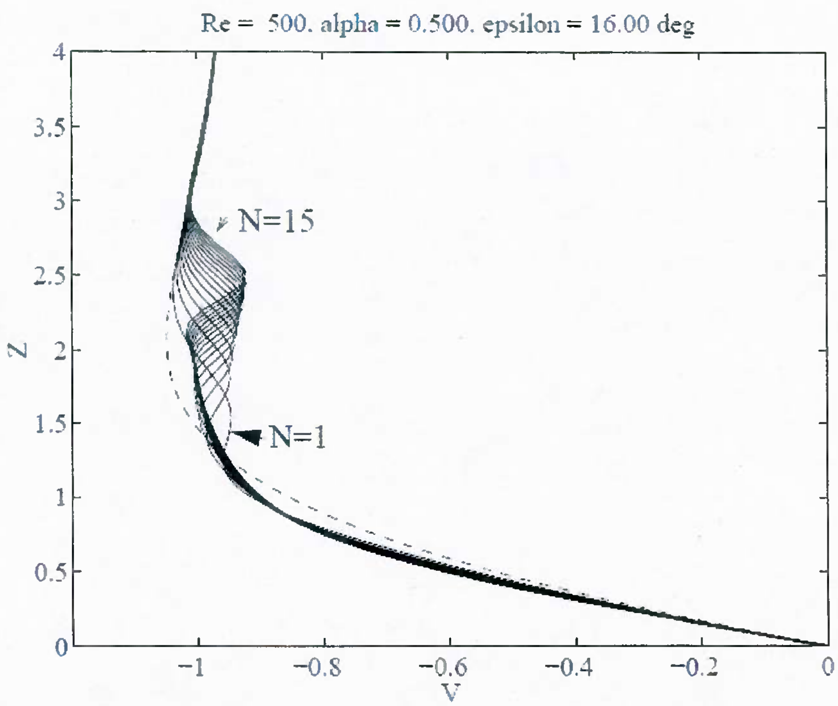
$0 \quad + A^2 q_{01}$ (mean flow modification)

$A q_{10} + 0 \quad + A^3 q_{11}$ (fundamental wavelength)

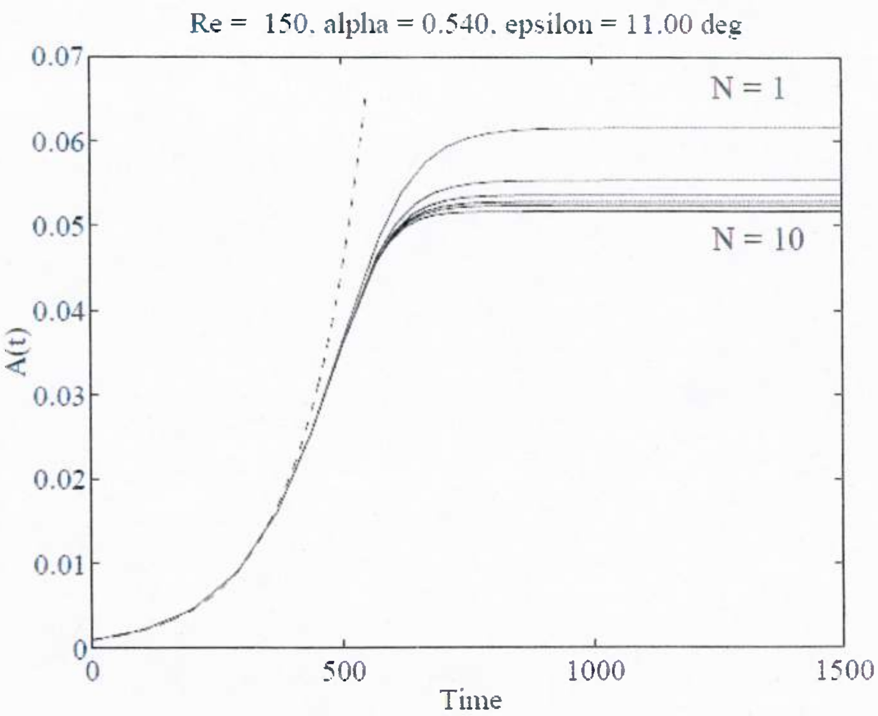
$0 \quad + A^2 q_{20}$ (1st harmonic)

$0 \quad + 0 \quad + A^3 q_{30}$ (2nd harmonic)

Low-Order Truncation Errors



Mean-flow Modification



Amplitude Estimation

Low-order truncation problems:

- Over-estimated amplitude
- “S-shaped” MF modification

Future plans

- Focus on the fluxes
  - De-trending
  - Scale separations
  - Skewness calculations
- Design a series of TODWL/CTV flights that focus on cloud free and partly cloudy MBLs where the CTV is deployed per in-flight findings using the TODWL.

Attachment 3

Report of University of Virginia Project Efforts

Investigation of the representation of OLEs and terrain effects within the coastal zone in the EDMF parameterization scheme: an airborne Doppler wind lidar perspective.

Stephan F.J. De Wekker
University of Virginia

Reporting period: 1 July 2012-30 June 2013

The planned tasks for year 2 of this project that involved subcontractor UVA were:

Task 2.1 - Planning of flights for field program (SWA, UW, and UVA) to optimize evaluation of EDMF parameterization.

Task 2.2 – Field program participation. UVA will provide radiosonde launches.

Task 3.1 – Processing and analysis (including algorithm and software development) and of new TODWL data after completion of field program

Task 3.7 – Analyze TODWL data and compare with Radiosonde date (UVA and SWA)

Accomplishments:

During year 2, a majority of the effort was in planning and conducting of TODWL research flights. The UVA contribution was focused on investigating OLEs and their representation in the EDMF scheme over land. Flights were conducted for this part over the Salinas Valley (1 research flight) and 7 flights were conducted over Dugway proving Ground in Utah as part of the ONR funded MATERHORN field campaign. UVA provided and launched about 20 radiosondes for these field campaign. The TODWL flight pattern that was developed for Dugway Proving Ground consisted of straight north-south and east-west legs at 12,000 ft and a sequence of low level flights. The legs were centered on Granite Mountain, a mountain ridge of about 1000 m high. A typical flight pattern is shown in Fig. 1. During the north-south and east-west legs, the airborne lidar was scanning in a step-stare pattern obtaining 12 radial velocity profiles during one full rotation. These data were processed to obtain u, v, and w wind components at 50-m vertical resolution. Between two full rotations of the scanner, the lidar was pointing straight down (nadir stares) resulting in accurate measurements of the vertical velocity. An example of the vertical wind profiles during a north-south leg is shown in Fig. 2. During this particular flight, upper-level winds were generally from southwesterly directions between 5 and 10 m/s. Around and below the height of Granite Mountain at 2 km, a drastic change in wind speed and direction can be observed.

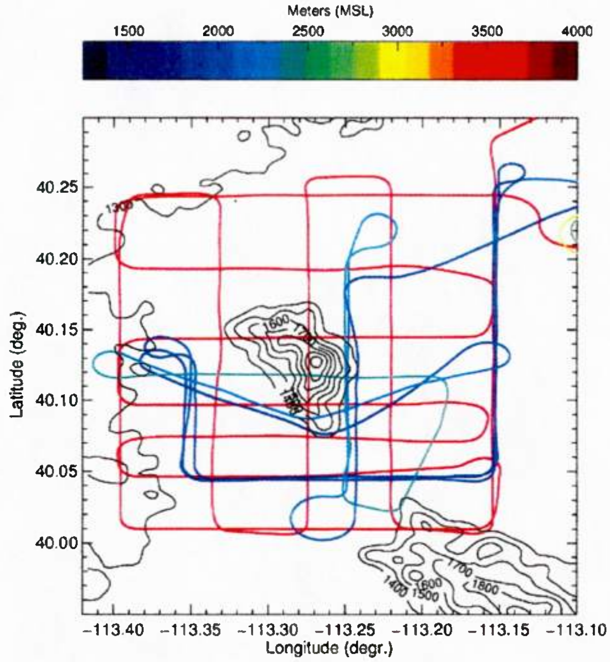


Figure 1: Flight pattern during RF04 with the colors indicating the height of the aircraft. Typically, a north-south and east west flight pattern was conducted to obtain vertical profiles of wind speed and direction, followed by low level flights for the prospecting of organized convective structures.

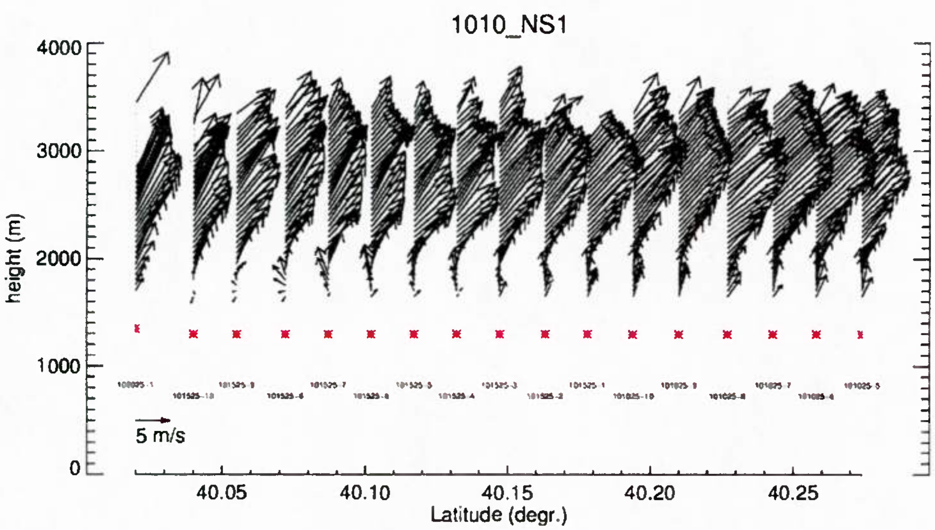


Figure 2: vertical profiles of horizontal wind along the easternmost N-S leg shown in Fig. 1.

The low level flights were designed to prospect for organized convective structures and for quantifying vertical heat and momentum fluxes associated with these structures.

Steve Greco (SWA) and Stephan De Wekker (UVA) have been performing simulations on a 64 processor cluster at UVA. In addition, De Wekker has started a collaboration with the Research Application Laboratory at the National Center for Atmospheric Research (NCAR-RAL) to perform 'very large eddy simulations' (VLES) with a 300 m grid spacing for the various days of the research flights. An initial comparison of the winds in a horizontal cross section shows that some important features of the observed winds are captured by the VLES (Fig. 3). A more detailed analysis and evaluation the VLES and of a mesocale model in which an EDMF scheme is implemented is planned for the third year of this project. Additionally, we are planning idealized numerical simulations using WRF-LES to simulate OLE's (in particular rolls) that will be used to test a theoretical model for OLE dynamics that has been developed by collaborator Foster (UW).

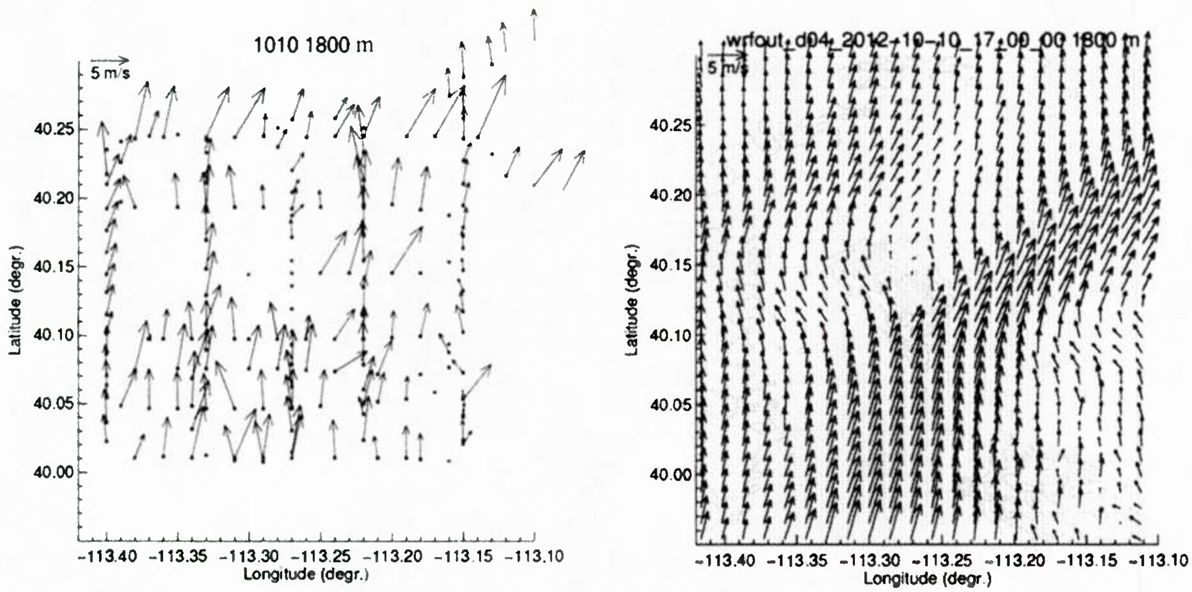


Figure 3: comparison between observed (left) and simulated (right) winds at 1800 m AGL during RF03.

A summary of the flights that were conducted in support of UPP and MATERHORN is shown in Figure 4. Six out of the seven flights were conducted under quiescent to moderate condition as indicated by the 700 and 850 mb winds on the flight days. RF07 was conducted under stronger synoptic forcing than other days. A major effort will be put in the third year of this project to investigate the presence of organized convective structures under these different conditions and the contribution of these structures to vertical heat and momentum fluxes. These investigations will also include a detailed analysis of surface fluxes obtained by in-situ turbulence sensors on the many towers that were deployed during MATERHORN. A post-doc (Sandip Pal) and a graduate student (Mark Sghiatti) at UVA will contribute to this effort during the next year.

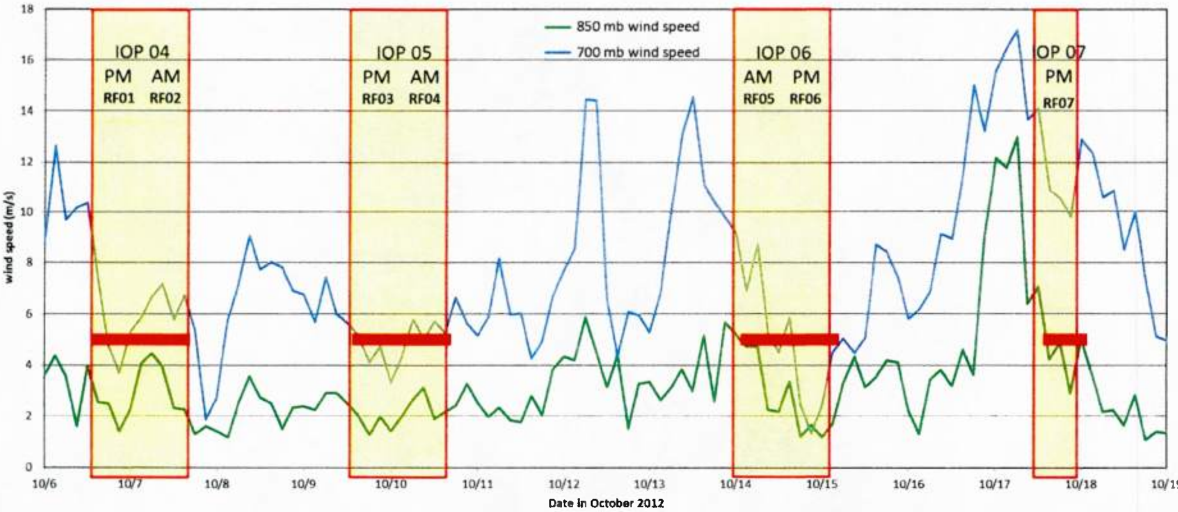


Figure 4: Summary of the 7 research flights conducted during MATERHORN in support of the UPP and MATERHORN projects. Winds at 700 and 850 mb provide an indication of the magnitude of the synoptic forcing during the various flight days. Flights were conducted during MATERHORN IOP's 4, 5, 6, and 7.

Publications related to the project:

De Wekker, S.F.J., G.D. Emmitt, S. Greco. K. Godwin, R. Foster, S. Pal, and H.J. Fernando, 2013: Wind and turbulence structure in the boundary layer around an isolated mountain: airborne measurements during the MATERHORN field study, Davos Atmosphere and Cryosphere Assembly (DACA), 8-12 July 2013.

De Wekker, S.F.J., J. Knievel, Y. Liu, G.D. Emmitt, S. Pal, B. Balsley, D. Lawrence, S. Hoch, C. Hocut, Y. Wang, and H.J.S. Fernando, 2013: Multi-scale flows and boundary layer structure during the morning transition period: a case study from the MATERHORN field study, Davos Atmosphere and Cryosphere Assembly (DACA), 8-12 July 2013.

Liu, Y., Y. Liu, G. Roux, J. Knievel, S.F.J. De Wekker, D. Zajic, and J. Pace, 2013: Nested-grid simulation and real-time forecasting experiments of complex terrain flows at US Army DPG with NCAR WRF RTFDDA-LES. 14th Annual WRF Users' Workshop, Boulder, CO, 24 – 28 June 2013.

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14. ABSTRACT
We have processed more than 50 hours of TODWL data from both the Monterey and DPG areas. We have begun combining the information from the TODWL, CTV and Twin Otter sensors to establish the relationship between the local fluxes and the energetic of LLJs and OLEs. We have also begun to modify the EDMF (Eddy Diffusivity and Mass Flux) parameterization to account for the differences between thermally driven convection and dynamically driven vertical transports.
The WRF model has been setup and run for the 7 MATERHORN missions and comparisons between the TODWL wind profiles and the model profiles have been completed for one day.
The OLE model has been modified to investigate "stacked OLEs" seen in the April 2007 datasets.

15. SUBJECT TERMS
OLE, EDMF, Doppler Wind Lidar

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